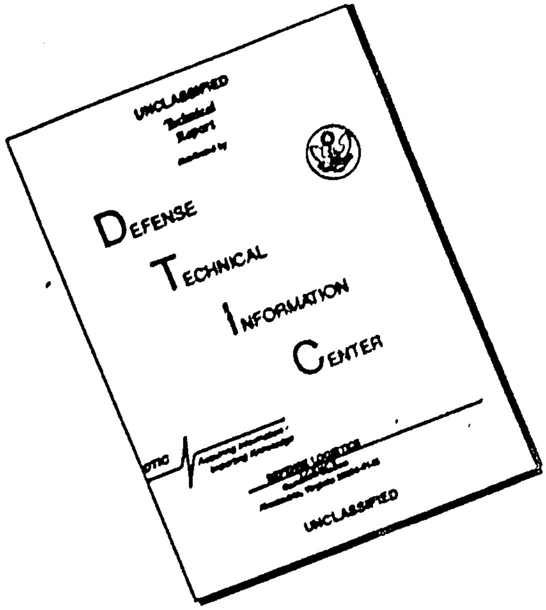
AGARD CONFERENCE PROCEEDINGS No. 203

on

Recent Advances in Space Medicine

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

(14) AGARD-CP-203

NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

(9) Conference proceedings,

(6) AGARD Conference Proceedings No.203

RECENT ADVANCES IN SPACE MEDICINE .

Edited by

(10) J. Colin

(11) Jan 77

Médecin Chef des Services
E.A.S.S.A.A.
5 bis Avenue de la Porte de Sèvres
75996 Paris-Armées, France

(12) 114 p.

Papers presented at the Aerospace Medical Panel Specialists Meeting held in Athens, Greece, 20–24 September 1976.

400043

1B

THE MISSION OF AGARD

The mission of AGARD is to bring together the leading personalities of the NATO nations in the fields of science and technology relating to aerospace for the following purposes:

- Exchanging of scientific and technical information;
- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
- Improving the co-operation among member nations in aerospace research and development;
- Providing scientific and technical advice and assistance to the North Atlantic Military Committee in the field of aerospace research and development;
- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field;
- Providing assistance to member nations for the purpose of increasing their scientific and technical potential;
- Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community.

The highest authority within AGARD is the National Delegates Board consisting of officially appointed senior representatives from each member nation. The mission of AGARD is carried out through the Panels which are composed of experts appointed by the National Delegates, the Consultant and Exchange Program and the Aerospace Applications Studies Program. The results of AGARD work are reported to the member nations and the NATO Authorities through the AGARD series of publications of which this is one.

Participation in AGARD activities is by invitation only and is normally limited to citizens of the NATO nations.

The content of this publication has been reproduced
directly from material supplied by AGARD or the authors.

Published January 1977

ISBN 92-835-0186-1

Printed by Technical Editing and Reproduction Ltd
Harford House, 7–9 Charlotte St, London, W1P 1HD

AEROSPACE MEDICAL PANEL

Panel Chairman: Major General H.S.Fuchs, GAF, MC

Panel Deputy Chairman: Médecin Général G.Perdriel, FAF

Panel Executive: Lt Colonel F.Monesi, IAF, MC

MEETING ORGANIZATION

Host Coordinator and Program Organizer: Col. C.E.Giannopoulos, HAF

CONTENTS

RAPPORT D'EVALUATION TECHNIQUE

par

J.Colin

Dans ce rapport d'évaluation technique nous essaierons d'abord de placer les communications présentées à cette session consacrée à la médecine spatiale dans le contexte général de cette discipline. Ensuite, nous tenterons d'en donner un bref résumé et d'en tirer quelques conclusions.

L'essentiel des objectifs de la médecine spatiale consiste à étudier les facteurs nocifs rencontrés au cours du vol dans l'espace et les moyens à mettre en oeuvre pour en protéger l'homme, à adapter les postes de travail des engins spatiaux aux possibilités humaines, et à mettre au point des critères permettant de sélectionner le personnel le mieux adapté aux conditions auxquelles il aura à faire face.

Le premier groupe d'investigations de la médecine spatiale concerne l'étude de l'action sur l'organisme des facteurs nocifs du milieu dans lequel évolue l'engin spatial. Ce milieu est caractérisé par la présence de rayonnements, ionisants ou non ionisants, dont l'homme est habituellement protégé, à la surface du globe terrestre, par l'atmosphère et la magnétosphère. Dans la présente session, aucune communication ne porte sur ce sujet.

Le deuxième groupe de recherches porte sur l'action sur l'organisme des divers facteurs rattachés aux mouvements du véhicule spatial et au fonctionnement des propulseurs assurant ces mouvements. Il s'agit principalement des accélérations et de l'absence de pesanteur. Cette dernière, qui représente l'aspect le plus spécifique de la vie dans un véhicule spatial en orbite ou en vol balistique, a fait l'objet de sept communications. Celles-ci peuvent elles-mêmes se subdiviser en trois rubriques:

(1) Action de l'absence de pesanteur sur l'appareil vestibulaire: le mal des transports. Trois communications portent sur ce sujet, soit directement (C-1), soit indirectement (C-2 et C-3).

(2) Le travail en absence de pesanteur. Trois communications y sont consacrées. L'une porte sur la nécessité de simuler les missions pour la programmation et l'entraînement (C-4), la deuxième développe l'intérêt de l'immersion comme méthode d'entraînement au travail en absence de pesanteur (C-5) et la troisième est consacrée à l'étude ergonomique des postes de travail de Spacelab (C-6).

(3) Action de l'absence de pesanteur sur les liquides organiques. La communication C-7 décrit une étude biostéréométrique des variations de volumes corporels régionaux effectuée sur les astronautes des trois vols de Skylab.

Le troisième grand chapitre de la médecine spatiale porte sur les problèmes soulevés par la vie en cabine close de dimensions restreintes. Ce vaste chapitre, qui a trait en particulier aux systèmes de maintien de la vie ("life support systems"), n'est que partiellement abordé par la communication C-6, qui fait un bref rappel des caractéristiques de l'environnement qui sera réalisé à bord de Spacelab.

Le quatrième grand chapitre de la médecine spatiale est consacré à l'étude des critères de sélection des astronautes. Ces critères se basent sur les résultats acquis par les études correspondant aux chapitres précédents. Quatre communications portent sur la sélection des astronautes scientifiques de Spacelab, au point de vue ophtalmologique (C-8), forme physique (C-9), et psychologique (C-10 et C-11).

Enfin deux communications sont un peu en dehors de ces quatre grands chapitres. La communication C-12 donne les bases expérimentales de l'utilisation d'hypnotiques par les équipages aérospatiaux. Elle s'applique aussi bien à l'aéronautique qu'à l'espace. Elle pourrait aussi être rattachée au troisième chapitre (vie en espace clos) dans le cas où une planification non circadienne des cycles travail-sommeil ne pourrait être observée. La communication C-13 est, quant à elle, consacrée à l'utilisation des techniques de télésurveillance mises au point pour les astronautes à la médecine préventive. Il s'agit là d'une "retombée" importante de la médecine spatiale.

Les différentes communications de cette séance étant maintenant placées dans le contexte général de la médecine spatiale, nous allons maintenant en faire une très brève analyse critique.

Le mal de l'espace relève d'un mécanisme qui n'est pas encore complètement connu. Dans sa communication, le Professeur Gualtierotti fait le bilan des observations effectuées sur l'homme et l'animal en absence de pesanteur et après le retour au sol, et en dégage un programme de recherches à effectuer dans l'avenir. Il s'agit en particulier de mieux comprendre la participation des canaux semi-circulaires, de constater si des altérations anatomiques apparaissent dans le vestibule, de préciser les modifications fonctionnelles déjà connues au niveau des otolithes, et d'approfondir le problème de l'habituation à l'absence de pesanteur au point de vue vestibulaire. Il n'est pas douteux qu'un tel programme apportera des éléments indispensables, soit à la sélection des astronautes, soit à une action pharmacologique sur le mal de l'espace. D.B.Cramer et ses collaborateurs ont montré qu'il était possible de diminuer la sensibilité au mal de l'air de sujets très

susceptibles, grâce à une adaptation progressive à la chambre à rotation lente, obtenue par l'exécution de mouvements de la tête au cours de l'augmentation de vitesse angulaire de la chambre. W.Hoffelt, en soumettant ses sujets à divers types de stimulations, a montré que le mal des transports n'était pas en relation avec une hypersensibilité de l'appareil vestibulaire, mais plutôt avec la façon dont les informations visuelles étaient reçues et interprétées. Ses résultats sont en accord avec la théorie du conflit. Ces deux communications sont fort intéressantes sur le plan du mal de l'air, mais on peut se demander jusqu'à quel point leurs conclusions sont applicables à l'absence de pesanteur, les mécanismes mis en jeu étant différents.

Le Lieutenant-colonel E.C.Burchard a montré dans sa communication que la simulation des missions spatiales était un des éléments nécessaires de la planification et de l'entraînement pour les missions du Spacelab. Son exposé s'appuie sur les simulations de missions de la navette spatiale effectuées depuis trois ans aux USA et met parfaitement en évidence la nécessité absolue de l'utilisation d'un simulateur pour aboutir à la planification soigneuse qui est nécessaire à la réussite du travail dans l'espace.

Le Docteur Oser a rappelé l'utilité de l'entraînement en immersion, bien qu'il ne s'agisse que d'une simulation partielle des conditions de travail en absence de pesanteur, en couplant cet entraînement en piscine avec un entraînement en vol parabolique et avec d'autres dispositifs de simulation partielle au sol. U.G.Munkelt et H.S.Jencks ont donné des détails très intéressants sur les postes de travail du Spacelab. Ils ont montré le soin avec lequel les études ergonomiques de ces postes ont été effectuées, en tenant compte des essais effectués en immersion dans l'eau et des observations effectuées sur Skylab en absence de pesanteur.

Le Squadron Leader Whittle a rapporté des résultats expérimentaux des vols de Skylab, concernant les variations de volume de secteurs corporels mesurés par méthode biostéréométrique. En dehors du fait que cette nouvelle méthode d'investigation a permis d'apporter des précisions intéressantes sur l'action de l'absence de pesanteur sur l'organisme, il apparaît que ses avantages techniques l'appellent à un grand développement dans les études médicales ou physiologiques.

Le médecin Lieutenant-colonel Daumann a proposé des critères ophtalmologiques de sélection pour les astronautes scientifiques de Spacelab. Il se base sur le fait que ces astronautes ne joueront pas de rôle actif dans la sécurité du vol et aboutit à des normes assez larges, que d'autres spécialistes estiment être insuffisamment sévères. Le Docteur K.E.Klein et ses collaborateurs P.Kuklinski et H.M.Wegmann ont fait une communication extrêmement intéressante sur la signification de la forme physique dans la sélection et l'entraînement des équipages de Spacelab. Ils ont à ces propos essayé de donner des éléments de réponse à la question: l'entraînement à l'endurance athlétique apporte-t-il un avantage pour les vols spatiaux? Des comparaisons expérimentales qu'ils ont faites entre des athlètes et des sujets simplement normaux soumis à un certain nombre de contraintes aérospatiales (hypoxie, accélérations, orthostatisme, absence de pesanteur simulée par immersion) et de l'observation des réactions des membres des équipages de Skylab avant, pendant et après le vol spatial, ils tirent la conclusion quelque peu inattendue que l'entraînement de type athlétique est plutôt désavantageux. Il n'est pas douteux qu'il sera nécessaire de tenir compte de ces constatations pour l'entraînement et les exercices en vol des équipages de Spacelab.

B.O.Hartman et R.C.McNee, se basant sur l'expérience qu'ils ont acquise dans la sélection psychologique pour le compte de la N.A.S.A., ont dégagé les caractéristiques psychométriques des astronautes. Leurs réflexions seront utiles aux psychologues européens qui seront chargés d'un travail similaire par l'Agence Spatiale Européene.

K.-M.Goeters s'est efforcé, de son côté, d'analyser les différences qui existent entre les missions qui ont été confiées aux premiers astronautes et celles que l'on confiera aux astronautes scientifiques de Spacelab. Ces deux catégories d'astronautes auront de ce fait nécessairement des origines et surtout des expériences aériennes fort dissemblables ce qui rend la sélection psychologique absolument indispensable. Il insiste en outre sur le fait qu'une telle sélection doit être effectuée sur un plan national, pour tenir compte des différences de culture qui peuvent rendre inefficace dans un pays, un test qui s'est avéré utile dans un autre.

Le problème abordé par le Wing Commander A.N.Nicholson et ses collaborateurs R.G.Borland, C.M.Clarke et B.M.Stone, n'est pas spécifique de la médecine spatiale et son intérêt déborde largement de son domaine. Il est en effet bien des cas où l'on est amené à envisager l'utilisation de drogues hypnotiques. Le problème majeur dans le domaine aérospatial réside dans l'existence possible d'effets secondaires venant diminuer les performances psychomotrices des équipages. Les auteurs se sont penchés expérimentalement sur la qualité du sommeil induit. Ils ont l'intention de poursuivre leur étude en comparant les effets secondaires. Les résultats qui seront acquis seront très utiles dans le choix de l'hypnotique à utiliser dans l'espace, lorsque, au début des missions en orbite, l'adaptation au nouvel environnement n'est pas encore réalisé et le sommeil difficile à obtenir.

Le Docteur W.L.Jones a clos la session consacrée à la médecine spatiale, en montrant que l'utilisation des techniques de télésurveillance utilisées pour les astronautes pouvait être d'une grand utilité pour la médecine préventive. Pour illustrer cette "retombée" de la médecine spatiale, il a décrit la surveillance médicale exercée sur le personnel de la NASA, donné les grandes lignes du "projet STARPAHC" de surveillance médicale des Indiens Papago, et des expériences de "Télémédecine" effectuées par la Marine américaine (R.M.D.S.). Bien que l'utilisation de techniques aussi sophistiquées ne permette pas une extension rapide immédiate de cette retombée de la médecine spatiale, son importance ne saurait être sous-estimée pour l'avenir.

TECHNICAL EVALUATION REPORT

by

J.Colin

This technical evaluation report will attempt first of all to place the papers read at this Space Medicine Conference in the general context of that discipline. This will be followed by a short summary of each of the papers and the conclusions to be drawn from them.

The main objectives of space medicine are to study the harmful factors encountered during space flight and investigate the means of protecting human beings from the effect of such factors, to adapt the work stations in spacecraft to suit human capabilities and to lay down criteria for selecting the personnel most suitable for working in the conditions which they will have to face.

The first major heading for investigations in the field of space medicine is concerned with studying the effect on the organism of the harmful elements in the environment in which the spacecraft operates. This environment is characterised by the presence of radiation, both ionising and non ionising radiation, from which human beings are normally protected on the surface of the earth by the atmosphere and the magnetosphere. No paper on this subject was presented during this Conference.

The second major research heading covers the effect on the organism of the various factors associated with the changing position of the spacecraft and with the functioning of the thrusters used for this purpose. The main factors involved are acceleration and weightlessness. The latter, which represents the most specific aspect of life in a space vehicle in orbit or during ballistic flight, forms the subject of seven papers, which can themselves be sub-divided into three main headings:

(1) The effect of weightlessness on the vestibular system: motion sickness. Three papers deal with this subject, either directly (C-1) or indirectly (C-2 and C-3).

(2) Working in conditions of weightlessness. Three papers cover this aspect. One paper refers to the need for mission simulation for purposes of programming and training (C-4), the second develops the value of immersion as a method of training personnel for working in a weightless environment (C-5), while the third is devoted to an ergonomic study of the work stations in Spacelab (C-6).

(3) The effect of weightlessness on the organic fluids. Paper C-7 describes a biostereometric study of the variation in volume of certain parts of the body carried out on the astronauts during the three Skylab flights.

Under its third major heading space medicine investigates the problems of living in an enclosed cabin of small dimensions. This vast area of research, which is concerned primarily with life support systems, is only partially dealt with in paper C-6, which reviews very briefly the characteristics of the proposed Spacelab environment.

The fourth major area of study in space medicine considers the criteria for the selection of astronauts. These criteria are based on the results obtained from the studies made in connection with the areas of research already mentioned. Four papers discuss the selection of the scientific astronauts for Spacelab from the ophthalmological (C-8), physical fitness (C-9) and psychological (C-10 and C-11) points of view.

Finally, two papers are slightly outside these four major headings. C-12 gives the experimental bases for the use of hypnotics by aerospace crews, and covers both aviation and space flight. It could also come under the third heading (living in an enclosed space) in cases where it was not possible to keep to a non circadian planning of the work/sleep cycles. The subject of C-13 is the application to the preventive medicine field of the telemonitoring techniques developed for astronauts. This is an important "spin-off" from space medicine.

The various papers read at this Conference having been placed within the general context of space medicine, a very short critical analysis of each paper will now be given.

Space sickness is associated with a mechanism which is not as yet fully understood. In his paper Professor Gualtierotti draws up a balance sheet of the observations made on humans and animals in conditions of weightlessness and after their return to Earth, and uses them as a basis for a programme of future research, aimed in particular at increasing our understanding of the part played by the semi-circular canals, at ascertaining whether the vestibule undergoes any anatomical changes, at clarifying the already known functional modifications at the otolith level and at studying in greater depth the question of acclimatisation to weightlessness from the vestibular point of view. There is no doubt that such a programme will provide essential data either for the selection of astronauts or for the effectiveness of drugs on space sickness. D.B.Cramer and his colleagues have shown that it was possible to reduce sensitivity to air sickness in very susceptible subjects by means of gradual adaptation to a slowly rotating room, achieved by making head movements during increases in angular velocity of the room. By subjecting his subjects to various types of stimuli, W.Hoffelt showed

that motion sickness was not related to hypersensitivity of the vestibular system, but rather to the way in which visual information was received and interpreted. His results agree with the conflict theory. These two papers are extremely valuable from the point of view of air sickness but it may be wondered to what extent their conclusions can be applied to weightlessness, which involves quite different mechanisms.

Lt Col. E.C.Burchard showed in his paper that space mission simulation was one of the essential elements in planning the Spacelab missions and in training the crews. His paper is based on the space shuttle mission simulations which the USA have been carrying out for the past three years and indicates fully the absolute necessity of using a simulator if the careful planning essential for the success of work performed in space is to be achieved.

Dr Oser referred to the usefulness of immersion training, although this is only partial simulation of the working conditions in a weightless environment, by coupling this training in a water tank with parabolic flying training and with other ground-based partial simulation devices. U.G.Munkelt and H.S.Jencks gave very interesting details about the work stations in Spacelab. They showed the great care with which the relevant ergonomic studies had been carried out, taking into account the water immersion tests and the observations made in Skylab in conditions of weightlessness.

Squadron Leader Whittle reported the experimental results of the Skylab flights concerning the variations in volume of certain parts of the body as measured biostereometrically. Apart from the fact that this new method of investigation has provided useful information on the effect of weightlessness on the organism, it would appear that its technical advantages mark it out for wider development in medical or physiological studies.

Lt Col. Dr Daumann suggested ophthalmological standards for selecting the scientific astronauts who are to work in Spacelab. He bases his suggestions on the fact that these astronauts will not be taking an active part in flight safety and arrives at fairly broad standards which other specialists consider are not strict enough. Dr K.E.Klein and his colleagues P.Kuklinski and H.M.Wegmann presented an extremely interesting paper on the significance of physical fitness in the selection and training of space aircrews. They tried to provide data for answering the question: Is previous training for athletic endurance an advantage for space flights? From the experimental comparisons between athletes and ordinary normal persons who were subjected to a number of aerospace constraints (hypoxia, acceleration, orthostatism, weightlessness simulated by immersion) and from observations of the reaction of the Skylab crews before, during and after their space flight, they draw the somewhat unexpected conclusion that training of the athletic type is more of a disadvantage. These findings will certainly have to be taken into account during the training and flight exercises of the Spacelab crews.

B.O.Hartman and R.C.McNee, who based their paper on the experience gained while conducting psychology selection tests on behalf of NASA, outlined the psychometric characteristics of astronauts. Their ideas will be valuable for the psychologists in Europe who will be asked by the European Space Agency to undertake similar work.

K.-M.Goeters has attempted to analyse the differences between the missions carried out by the first astronauts and those to be performed by the Spacelab scientific astronauts. The backgrounds, and particularly the air experience of these two groups of astronauts, will necessarily have been very dissimilar, a fact which makes it absolutely essential that they should be selected on the basis of psychology tests. He also stressed the fact that this selection should be made on a national level in order to allow for any cultural differences which may make invalid in one country a test which has proved useful in another country.

The problem discussed by Wing Commander A.N.Nicholson and his colleagues, R.G.Borland, C.M.Clarke and B.M.Stone, is not specifically related to space medicine and its interest lies largely outside that field. There are in fact many instances in which the use of hypnotics can be contemplated. The major problem in the aerospace field lies in the possible existence of side-effects which may lower the psychomotor performance of crew members. The authors have made experimental studies on the quality of the sleep induced. The results obtained will be very useful when deciding on the type of hypnotic to be used in space if, at the start of their orbital missions, crew members have not become fully adapted to their new environment and have difficulty in sleeping.

Concluding the Conference, Dr W.L.Jones showed that the use of the telemonitoring techniques developed for astronauts could be very valuable in the preventive medicine field. To illustrate this "spin-off" from space medicine he described the medical monitoring of NASA personnel, outlined the STARPAHC project for the medical monitoring of the Papago Indians, and the "telemedicine" experiments carried out by the US Navy (RMDS). Although the use of such sophisticated methods does not make for the immediate rapid extension of this spin-off from space medicine, its importance for the future cannot be underestimated.

INVESTIGATION OF THE EFFECT OF FREE FALL ON THE VESTIBULAR ORGAN AND OF ITS POST-FLIGHT READAPTATION AS PART OF THE SHUTTLE PROGRAM.

A CONTRIBUTION TO BASIC VESTIBULAR PHYSIOLOGY AND TO THE PROBLEM OF SPACE SICKNESS.

Torquato Gualtierotti, Head, IInd Department of Human Physiology, University of Milan Medical School, Via Mangiagalli n. 32, 20133 MILANO, Italia.

SUMMARY

The program outlined here intends to help in understanding certain facts of basic vestibular physiology and also to tackle the problem of space sickness.

1. Space sickness.
   With the Apollo program the increased size of the spacecraft and the increased head motions due to working in space induced symptoms of space sickness. With the Shuttle-Spacelab program untrained people will have major problems. Studies are therefore enhanced on mechanisms on space illness based on vestibular reaction to free fall conditions.

2. Basic Research.
   Space provides an exclusive tool for basic physiological studies of the vestibular organ as it allows for the first time investigation of the organ function after neutralization of the gravitational pull. A space experiment monitoring the single vestibular statoreceptors output indicated important reversible and unreversible changes. The significance of such changes are discussed consequently. A Vestibular Research Function program will be carried out during the Shuttle Spacelab missions.

INTRODUCTION

General physiology of the labyrinth.

The labyrinth, the non-auditory portion of the inner ear, is a highly specialized receptor system having 4 main functions:

1) To maintain the equilibrium through providing the input to the subjective sensation of motion and spatial orientation.
2) To guide the postural control system by adjusting muscle activity, preventing, for example, falling over.
3) To control eye movements in order to stabilize vision during head motion, helping to fix the image on the retina.
4) To exert a dominant influence on the autonomic nervous system which controls the cardiovascular and visceral functions.

The mode of action of the labyrinth corresponds to a closed-loop feedback system controlling movements of the head. A corrective head movement is used to cancel the "closed-loop error" which indicates departure from equilibrium, or a planned position or movement.

The input-output relationship of the vestibular system has been regarded for a long time as following the Weber function and its integrative form (Fechner law) as do the other sensory receptors.

Recently, however, both in the psycho-physical field, and especially in the field of sensory neurophysiology, the Weber function has been deeply criticized [8] especially for a weak stimulus. It appears that the input-output function of a sensory system is better described by a sigmoid curve than by the logarithmic curve that follows the Fechner law[4].

The consequence of this is that the maximum gain of the system corresponds to the middle of the response curve, while at either end the gain is reduced.

Different parts of the labyrinth respond to different acceleratory inputs. Classically, the semicircular canals respond to angular acceleration and the otoliths to a combination of gravitational and inertial forces (linear acceleration) so that the otolith receptors measure the magnitude and the direction of the vector $\bar{g} \pm \bar{a}$ (the gravitational vector plus or minus the linear acceleration vector).

By itself the otolith system is not able to distinguish between gravity and linear acceleration, but it interprets as a tilt even the gravito-inertial forces resulting from head movements.

Recently, however, this rigid classification of linear and angular acceleration sensors

has been doubted and cross coupling between the two systems is evident. Lowenstein (1972)[7] described the influence of gravity on semicircular canal function directly, showing that the tilt angle of the head modifies the firing rate of the canal nerves.

On the other hand, angular acceleration will affect the otolith organ too, by rotating the gelatinous mass including the otolith stones with respect to the macula.

An additional proper input to all vestibular sensors is provided by vibrations[6]. Specialized receptors, probably situated in the sacculus, respond only to vibration, and are not affected by linear acceleration or gravity. Semicircular canals respond to low frequency vibrations, below 0.5-1 Hz. while specialized otolithic receptors can respond to frequencies up to 500 Hz.

As already mentioned, the output of the vestibular system directly controls eye movement. It is therefore obvious to try to assess the vestibular functions by studying visual responses to head movement (nystagmus, oculogyral illusion, Otolith Test Goggle). However, to interpret the data obtained in this way it is necessary to remember that, starting from the secondary neurons (vestibular nuclei), along the vestibular-ocular pathway (which in man and superior mammals includes a cortical element), various vestibular and extravestibular afferents converge at various levels and tend to alter the vestibular output. This technique therefore studies an integrated motor response; the vestibular nerve is but one input to this system.

THE LABYRINTH AND SPACE FLIGHT.

Background.

The importance of the labyrinth to orbital and inertial flights is obvious. The neutralization of the effects of the gravity vector will deprive the statoreceptors of the otolith system of their primary input during steady positions of the head, while during movement the inertial forces will still exist.

This last event would also change the stimulus qualitatively. The $\bar{g} - \bar{a}$ gravity-inertial vectors tend to rotate when the two accelerations are not in the same plane. If the $\bar{g}$ force is eliminated and only the inertial force remains, the vector will change in magnitude but not in direction during any given unidirectional movement of the head.

In evaluating comparatively the observations of apparently equivalent tests on ground and during "0" g conditions, this factor has to be kept in mind (see later).

The interplay between the space environment and the vestibular function has two consequences:

a) Possible vestibular malfunction during orbital and inertial flight alters the behaviour and the performance of the astronauts in space and results in the so-called space sickness (stomach awareness, according to the definition introduced recently by the Office of Life Sciences of NASA).
b) Space provides an exclusive tool for basic physiological studies of the vestibular organ as it allows for the first time investigation of the organ function outside the gravitational field and therefore after neutralization of the gravitational pull.

Observed facts so far.

On integrated responses.
Humans.
The several hundred hours during which a number of astronauts and cosmonauts have been exposed to weightlessness during orbital and inertial flight provide a wealth of information on the alteration of the vestibular performance provoked by the absence of the gravitational pull.

1) Space sickness occurred in some astronauts and cosmonauts for periods of 3 days and longer. The space sickness symptoms were more pronounced and more frequent as the movements of the astronauts and cosmonauts increased. In fact, fast head movements during the first days of space flight easily caused vertigo , nausea and stomach awareness[2]. In Skylab II the crew spent the first three days of the space flight in the command module, being less mobile, and there was an absence of motion sickness, whereas in all crew member of Skylab III there were marked symptoms of space sickness during the first three days as relatively free movement was possible.
2) After three days or longer, habituation normally took place with disappearance of the space sickness syndrome. However, during the Skylab III mission, episodes of space sickness were still observed during extravehicular activity and in the workshop.
3) Tests performed on crewmen especially devised to explore the semicircular canal functions (rotating chair, oculogyral illusion: Experiment M-131 in Skylab III by Graybiel

et al.1974[5]) after the period of habituation showed that all crewmen were behaving almost normally.
Furthermore, they were free of symptoms in the Barany test showing that a lower susceptibility to motion sickness was present during flight, although symptoms of space sickness were shown in the workshop in the same period.
4) After flight, a vestibular readaptation syndrome has been observed in crewmen. Postural equilibrium, with the eyes closed, showed a considerable alteration: the capability of maintaining balance on a rail was deeply impaired after flight in all crewmen tested. Recovery to preflight baseline performance levels was complete only at the end of 2-3 weeks, obviously indicating an after-flight alteration of the vestibular sensory mechanism requiring a long time to readjust.

Fishes.
In Skylab III, an experiment by Von Baumgarten [1] showed strong disorientation (swimming loops) of two minnows during the first 3 days of the mission. After this period vestibular habituation seemed to take place but during the entire 21 days of the mission, disorientation of the fish reappeared when their container was slightly shaken.

Basic research at end-organ level
In OFO-A experiment[3] the otolith controlled activity at rest or under the influence of a low intensity constant vibratory stimulation, and the responses to pre-programmed centrifuge spin cycles of single 1st-order axons in the vestibular nerve of the bullfrog were recorded for up to 7 days through extracellular microelectrodes in the 1g earth gravitational field and in ab orbital satellite (10^{-4} - 10^{-3} g max.).
During the recording period 2 bullfrogs, intact but for the partial paralysis of the 4 limbs, were kept under standard environmental conditions (PO_2, temperature, illumination, pressure, acceleration) in a specially built experimental container completely filled with water in which the animals were submerged for the duration of the experiment. The environmental variables indicated above and the EKG were monitored continously.
The following results were obtained:
In orbit a significantly larger fluctuation of unit activity in the absence of any stimulus was observed, as well as a periodical change in the gain of the responses to the preset stimulus and to vibration. Generally, the response fluctuated from values above to values below the response typical on the ground. However, the most striking effect of weightlessness was a reversible change in the mode of response to the experimental stimulus from tonic to phasic and vice versa. This change of mode did not disappear after 6 days of weightlessness in orbit, whereas the resting activity reverted to normal after 4 to 5 days of orbital conditions.

DISCUSSION OF THE ABOVE DESCRIBED RESULTS AND CONCLUSIONS.

The observations made studying the integrated responses in humans and lower animals and those of the single end-organ units seem to correlate well,showing the importance of performing parallel researches in the same field at different levels. In fact it appears that an important change involving the otolith part of the vestibular organ is the result of exposure to weightlessness, while the semicircular canals seem to be less effected. This is shown by the negative results of the rotating chair accompanied by symptoms of space sickness.

One point to be considered in evaluating the latter experiment is the previsouly mentioned qualitative difference of the stimulus during rotation performed on the ground to that in orbit, namely the lack of the angular shift of the $\bar{g} - \bar{a}$ vector (see previous chapter).

The involvement of the otolith system with space sickness is further supported by the alterations in the postural equilibrium of Skylab III and IV crewmen following return to the ground, and by the renewal of the looping swimming in the minnows after habituation when subjected to a slight motion. Direct evidence of the alteration of the otolith end-organ is provided by the OFO-A experiment. However, as no semicircular canal units were included in those studied in the OFO-A flight there is no confirmation so far of the non or minor involvement of the semicircular canals in the vestibule reaction to weightlessness.

All results seem to indicate a certain degree of habituation, in crewmen, in fish and partially in the vestibular statoreceptors. The time course of this habituation is within 3-5 days in all cases.

There are indications a) that this habituation is not complete; b) that as a consequence a readaptation vestibular syndrome is present after return to ground.

The first point is shown by persistent space sickness syndrome in astronauts even after the period of habituation, in particular conditions (extravehicular activity, performing some task in the workshop of Skylab III) and in the fish, as indicated above.

The second, rehabituation, is shown by aftereffects of different kinds lasting from 3 days to 3 weeks after return to the ground. The investigation at the end-organ level performed during OFO-A might help in the understanding of some of the points indicated above. The activity at rest, in fact, of the unit belonging to the otolith system not only normalizes its variability, reverting to the kind of frequency fluctuation that is typical on the ground, but also the mean level of the activity itself returns to normal after 4-5 days in orbit.

This may be the neural equivalent of the habituation process at the level of the end-organ itself. If the organ is not stimulated by movement of the head the basic activity of the unit is the same as that on the ground. If however the head is moved, the altered responses of the single units change the normal response pattern of the output of the end-organ. This change of behaviour does not seem to show habituation, at least within the first six days of weightlessness. It is therefore understandable that space sickness syndrome appears again when movements are performed.

OUTLINE FOR THE VESTIBULAR SPACE PROGRAM THROUGH SERIES OF SHUTTLE MISSIONS.

In setting the recommendations for a life science study in the shuttle program, the Office of Life Sciences of NASA headquarters indicated at point No. 2 the following: 'Determine the cause of and the mechanism involved in the observed "stomach awareness" associated with early exposure (hours, persisting up to 3 days) after achieving orbit and determine the efficacy of selected preventive and/or therapeutic measures'.
From all the observations described above it follows that the origin of space sickness is not yet clear. It seems to be related however with a malfunction of the vestibular organ.

Anatomical changes.

The first question is: are the alterations at vestibular level only functional after a long exposure to free fall, or are there structural changes?
As far as I know, there are no histological and ultrastructural studies assessing the structural effect of "0" g on the vestibule. A possible effect of a prolonged stay in space might be a change of the otolith mass either from a loss of calcium or from an increased density of the othocone texture. It is known that the otolith stones show changes when the animal is maintained for a long term at 2 to 4 g. It is quite possible that free fall may produce some changes too. Degenerative alterations of the end cell and/or the nerve fibers, and the supporting structures of the macula might also be present. More subtle changes in the synaptic junctions, both afferent and efferent, in the macula could be transitory in "0" g corresponding to the reversible change of nerve activity that has been found. The basic otolith membrane might also change both structurally and in configuration.

As none of these possible histological alterations has been investigated so far, one profitable line of research for the future space program would be to expose for a prolonged period of up to 30 days, in the shuttle program, various animals, from frogs to mammals, to the free fall condition and perform histological and ultrastructural studies on the vestibular organ of such animals. Some of the alterations indicated above can be evaluated by means of post-flight histology with post-flight fixation, i.e. the measurement of otolith mass after prolonged exposure to "0" g and of any permanent or long-term degenerative changes in the macula structure.

Synaptic alterations and membrane attitudinal changes require in-flight fixation. This can be achieved by means of an implanted tantalum cannula and direct perfusion of the labyrinth with gluteraldehyde followed by total immersion of frog in gluteraldehyde at 4^{o}C. for up to 2 days before return to earth, where the preparations (perhaps up to 10 animals) would have to be processed for ultrastructural study in a well-equipped laboratory. Groups of several animals can be maintained for 30 days in orbit and the animal processed periodically both during the flight and after-flight periods.

The post-flight tests do not require any special instrumentation, whereas the periodical in-flight tests will require the insertion of the cannula only.

Functional studies.

All the indications coming from the results described above seem to point to the otolith system as being especially responsible for space sickness. However, whereas direct evidence exists (OFO-A experiment) that a malfunction of the otolith receptors is present, there is no equivalent information of the behaviour, in free fall, of the semicircular canal units and of the specialized cells that respond to vibration. Although, as indicated

above, the semicircular canal seems to show either a normal responses in free fall or even a higher threshold to stimulation, it is not possible at present to reach any conclusion on this point.

An additional line of research therefore appears to be a comparative simultaneous study of semicircular and vibratory units together with the otolith receptors. This does not require any special change of the OFO-A technique, as primary neurons relative to the semicircular canal and to the vibratory unit can be picked up in the vestibular nerve as easily as the primary neurons corresponding to the otolith units. Even if one cannot easily see how the mechanical transducing mechanism of the semicircular canals might be altered by the free fall condition, a change of the basic activity at rest of the semicircular canal units might still be present, either through a direct effect of the efferent control system or through an indirect influence of the changes observed in the otolith system owing to the cross correlation between the two organs. An increase or decrease in frequency of the activity at rest away from the optimal point might decrease the gain of the semicircular canal units and therefore explain, for instance, the higher threshold to rotation shown in orbit by the crewmen of Skylab III.

The lack of motion sickness may be due to this or to the fact that these particular units may not undergo the change of behaviour recorded from the otolith end-organ.

The same kind of reasoning might be applied to the investigation of the units responding selectively to vibration. These receptors, contrary to the recent information regarding the semicircular canals, seem to be indifferent to gravitational forces[6].

From the basic science point of view, this may give important information on the cross-correlation effect between the three different sections of the vestibular organ at the single unit level.

The habituation problem.

Some habituation of the vestibular behaviour in free fall seems to be established. Some uncertainty however exists on how complete it might be, as undoubtedly the response to motion indicates some persistent alteration even after 21 days of free fall. The direct evidence on the otolith unit presented by the OFO-A experiment indicates that some parameters (activity at rest of the single unit) show definite habituation within 4-5 days, whereas some do not (change of mode in the response to a set stimulus).

To understand this problem the main question is: what is the chief effect of free fall on the otolith end-organ? There is no doubt that the only sure change provoked by free fall is the mechanical lifting of the otolith bodies which will free the membrane from their weight. This unloading of the membrane in free flight would probably change the mechanical properties of the macula itself.

This alteration itself could not be spontaneously changed in weightlessness, and could only be overcome by applying some sort of linear acceleration to the system. Barring any other factor the end-organ would be permanently impaired.

It is known however that the vestibular end-organs are controlled by an efferent feedback mechanism capable of changing their basic activity. The input of this efferent system can be either vestibular or extravestibular.

An interaction between mechanical changes (membrane unloading) and the efferent feedback control might exist and might in the long term be able to restore some of the basic activity of the receptor cells.

. Although the role of the vestibular efferent system has not been fully investigated yet a working hypothesis on this mechanism as being responsible of the habituation at the vestibular organ level, can be accepted.

Both habituation of the activity at rest and change of mode in the response to a set stimulus might be the result of a change of adaptation: this is still a very obscure process by which the activity of a cell, after being altered by a constant stimulus, tends to return spontaneously to its resting state.

The phasic and tonic statoreceptors are in fact classified on the basis of their adaptation being either complete (phasic) or incomplete (tonic).

The apparently spontaneous change in the same receptor cells, from phasic to tonic and vice versa, observed during the exposure to free fall (OFO-A experiment) is a challenge to the basic physiology of the labyrinth and might be one of the factors causing the renewal of space sickness during movement after habituation. A third line of research therefore might consist in (1) checking out the changes in the mechanical transducing mechanism of the otolith cells during free fall by applying a known long-term load after an extended period of weightlessness, for instance by centrifugation, and observing the effect on the basic frequency of discharge at rest and the response to acceleration,and

(2) by studying the efferent feedback action on the adaptive process by pharmacological efferent blockage.

The two experimental procedures can be used separately and together to determine the relative importance of the two phenomena.

After flight functional studies.

The shuttle program allows the recovery of the specimen and therefore an extended study can be performed after the flight both from the functional and anatomical point of view.

It is suggested the animals be kept in the same life supporting system and such tests be performed in the days following the return to the ground in order to study rehabituation to the 1g gravitational field.

Extension of the research work described in 'Functional studies'; 'The habituation problem' and 'After flight functional studies' from frogs to mammals.

All the work described above is to be performed in frogs first: then it is planned to repeat the same experiment on mammals, starting from guinea pigs as these animals are well known from the point of view of vestibular physiology and surgically do not present any difficulty.

Squirrel monkey could then be used as these animals are considered more similar to man although of small enough size not to require large life-supporting systems. However, micro electrode implant in the vestibular nerve in squirrel monkeys, as generally in all kinds of monkeys without the ablation of a portion of the cerebellum, is still not feasible, and appropriate surgery has to be studied. This part of the program cannot be described in a more detailed form as a definite plan will be possible only after obtaining results on frogs.

Experimentations on humans.

For the same reasons that have been indicated for the experiment program on animals, it will be necessary to be able to distinguish as clearly as possible between the semicircular canal effect and the otolith system activity in space.

An experiment has been proposed by Dr. Von Baumgarten by which human subjects can be linearly accelerated along an X-axis, while being able to change attitude around a 360^{o} solid angle; this experiment might provide a partial answer to this problem as in this way the otolith end-organ and not the semicircular canal will be stimulated. Recently ESA approved the construction of the "Sled" a linear accelerator to be in general use in the Space lab jointly in the ESA and NASA vestibular progam.

SUMMARY OF PROPOSED VESTIBULAR RESEARCH OUTLINES.

ON ANIMALS

1) One profitable line of research for the future space program would be to expose, for a prolonged period of up to 30 days in the shuttle program, various animals from frogs to mammals, to free fall condition and perform histological and ultrastructural studies on their vestibular organs. Some of the alterations indicated above can be evaluated by means of post-flight histology with post-flight fixation, i.e. the measurement of otolith mass after prolonged exposure to "0" g and of any permanent or long-term degenerative changes in the macula structure.
Synaptic alterations and membrane attitudinal changes require however in-flight fixation. This can be achieved by means of an implanted tamtalum cannula and direct perfusion of the labyrinth with gluteraldehyde followed by total immersion of the frog in gluteraldehyde at 4^{o}C. up to 2 days before return to earth, where the preparations (perhaps up to 10 animals) would have to be processed for ultrastructural study in a well-equipped laboratory. Groups of several animals can be maintained for 30 days in orbit and the animal processed periodically both during the flight and after flight periods.
The post-flight tests do not require any special instrumentation, whereas the periodical in-flight tests will require the insertion of the cannula only.

2) A second profitable line of research appears to be a comparative simultaneous study of semicircular and vibratory units together with the otolith receptors. This does not require any special change of the OFO-A technique as primary neurons relative to the semicircular canal and to the vibratory unit can be picked up in the vestibular nerve as easily as the primary neurons corresponding to the otolith units.
Even if one cannot easily see how the mechanical transducing mechanism of the semicircular canals might be altered by the free fall conditions, a change of the basic activity at rest of the semicircular canal units might still be present either through a direct

effect of the efferent control system or through an indirect influence of the changes observed in the otolith system owing to the cross correlation between the two organs.
An increase or decrease in frequency of the activity at rest away from the optimal poiny might decrease the gain of the semicircular canal units and therefore explain, for instance, the higher threshold to rotation shown in orbit by the crewmen of Skylab III.
The lack of motion sickness may be due to this or to the fact that these particular units may not undergo the change of behaviour recorded from the otolith end-organ.
The same kind of reasoning might be applied to the investigation of the units responding selectively to vibration.
These receptors, contrary to the recent information regarding the semicircular canals, seem to be indifferent to the gravitational forces [6].
From the basic science point of view this may give important information on the cross correlation effect between the three different sections of the vestibular organ at the single unit level.

3) A third line of research might consist in (1) checking out the changes in the mechanical transducing mechanism of the otolith cells during free fall (and the efferent feedback action on the adaptive process) by applying known long term load after an extended period of weightlessness, for instance by centrifugation, and observing the effect on the basic frequency of discharge at rest and the response to acceleration of the vestibular units, and (2) by studying the efferent feedback action on the adaptive process by pharmacological efferent blockage.
The two experimental procedures can be used both separately and together to determine the relative importance of the two phenomena.

4) After flight functional studies.
The shuttle program allows the recovery of the specimen and therefore an extended study can be performed after the flight both from the functional and anatomical point of view. It is suggested that the animals be kept in the same life supporting system and such tests be performed in the days following the return to the ground in order to study rehabituation to the 1g gravitational field.

ON MAN

5) For the same reasons that have been indicated for the experimental program on animals it will be necessary to be able to distinguish as clearly as possible between the semicircular canal effect and the otolith system activity in space.
An experiment has been proposed by Dr. Von Baumgarten by which human subjects can be linearly accelerated along an X-axis, while being able to change attitude around a 360° solid angle; this experiment might provide a partial answer to this problem as in this way the otolith end-organ and not the semicircular canal will be stimulated.

REFERENCES

1) BAUMGARTEN, von, R.J., SIMMONDS, R.C., BOYD, J.P., GARRIOT, O.K. The effect of weightlessness on the spatial orientation of fish during the second manned skylab mission. Proceedings of the Congress of the German Physiological Society in Hannover, March 1974. Pflügers Archiv.

2) BERRY, C.A. Summary of medical experience in the Apollo 7 through 11 manned space flights. Recent advances in Aerospace Medicine proceedings XVIII Inter. Congress Aviation and Space Medicine, Amsterdam, 3-41 (1969).

3) BRACCHI, F., GUALTIEROTTI, T., MORABITO, A. and ROCCA, E. Multiday Recordings from the Primary Neurons of the Statoreceptors of the Labyrinth of the Bull Frog. The effect of an Extended Period of "Weightlessness" on the Rate of Firing at Rest and in Response to Stimulation by Brief Periods of Centrifugation (OFO-A Orbiting Experiment). Acta Otolaryngol. Suppl. 334, 1-27, 1975

4) GALANTER, E. "Contempory Psychophysics" in Brown et al. "New directions in psychology" New York, 1962, Holt, Rinchard and Winston Inc.

5) GRAYBIEL ET AL. II Skylab Life Sciences Symp. Lyndon B. Johnson Space Center, Houston, Texas, 27-29 August 1974, pp. 9-10

6) GUALTIEROTTI, T. Unidirectional response of statoreceptors to vibration. A mean for artificial gravity in space flight. Proc. VIII Int. Symp. Space Technology and Science, Tokyo, 1969, 1193-1200.

7) LOWENSTEIN, O. "Physiology of vestibular receptors" in Pompeiano and Brodal "Basic aspects of central vestibular mechanisms". Amsterdam, 1972, Elsevier Press.

SUCCESSFUL TRANSFER OF ADAPTATION ACQUIRED IN A SLOW ROTATION ROOM TO MOTION ENVIRONMENTS IN NAVY FLIGHT TRAINING

D.B. Cramer, A. Graybiel and W.J. Oosterveld
Naval Aerospace Medical Research Laboratory
Pensacola, Florida, U. S. A.

SUMMARY

Two flight students, grounded for the reason they were highly susceptible to motion sickness, completed their training after gradually adapting to 10 rpm, achieved by executing head movements during small stepwise increases in angular velocity. Subject 1 executed a total of about 77,000 head movements within a period of five months and Subject 2 executed about 108,000 head movements within a period of 42 days. The transfer of the adaptation acquired in the laboratory to most motion environments aloft was good; the notable exception involved weightless maneuvers in the case of Subject 1. Both were on flight status when contacted recently. The opportunity was taken to assess the current motion sickness susceptibility in Subject 1 in the fall of 1975. He reached our (mild) motion sickness endpoint, in the rotating room, at 17 rpm; the average endpoint is 7-8 rpm. Some practical and theoretical implications are discussed.

INTRODUCTION

If a person riding in a slowly rotating room makes a head movement outside the plane of the platform's rotation, cross coupled accelerations are generated which stimulate the vestibular apparatus in an unusual way. In the stationary state, head movements are associated with a pattern of accelerations that produce vestibular sensations consistent with the visual and propioceptive sensations associated with these head movements through past experience. By adding rotation, the vestibular sensations associated with the same head movements now include those sensations produced by the cross coupled accelerations. This produces a situation where the vestibular sensations are no longer consistent with the past visual and proprioceptive sensations. The subject's reactions to this unusual state can be grouped into two classes (1). The first class consists of reflexive reactions such as nystagmus, tumbling or turning sensations, and certain visual illusions. The first class seems to be a direct response to vestibular stimulation. A second class of responses less directly related to the vestibular stimulation constitutes the signs and symptoms of motion sickness. Inasmuch as these signs and symptoms have their immediate origins in non-vestibular systems, one must postulate a facultative linkage between vestibular and non-vestibular systems as an important element in the causation of this form of motion sickness (1). The signs and symptoms arising from this unusual vestibular stimulation have been well studied and a sensitive grading method is available (2).

It has been shown that subjects who perform sufficient head movements at one rpm increments can asymptomatically reach high angular velocities which would otherwise be intolerable (3). By having the subject execute a schedule of head movements at each increment in angular velocity, one has a simple method of providing adaptation to rotation. This scheme is called an incremental adaptation schedule. If the stress level of the incremental adaptation schedule is excessively high, the incidence of motion sickness will force the termination of the adaptation. Although the relationship between adaptation and motion sickness is not well understood, it is possible, using sufficiently small increments in rpm to achieve adaptation without overt symptoms of motion sickness.

Subsequent experience with incremental adaptation (4) has shown that this acquired adaptation has two components. The first to occur is a direction specific adaptation which decays in hours after the cessation of rotation. This direction specific adaptation provides increased tolerance to rotation only in the direction employed in the incremental adaptation schedule. It is also associated with a reduced tolerance to head movements at zero velocity and an even lower tolerance to head movements performed with rotation in the opposite direction. The rather rapid decay of the direction specific adaptation reveals a second component of adaptation which is not direction specific and decays slowly over days. This second component of adaptation is not associated with symptoms at zero velocity and does afford increased tolerance to head movements performed with rotation in the opposite direction. This second component of acquired adaptation is of practical interest since it decays slowly and is not stimulus specific.

A method of acquiring adaptation to unusual vestibular stimuli which is both persistent and not stimulus specific could be put to immediate practical use. Not infrequently, student aviators are dropped from flight training because of repeated episodes of severe air sickness. It is reasonable to assume that in their situation the stimulus level is so high that the prompt emergence of air sickness does not permit the occurrence of any significant adaptation. A similar situation may be created in the laboratory by repeatedly exposing the subject to a high angular velocity without the benefit of incremental adaptation. To test the practical usefulness of this phenomenon, it was decided to determine whether laboratory conducted incremental adaptation could be beneficial to student aviators with a history of severe air sickness.

MATERIALS AND METHODS

Subjects for this experiment were two flight students who were dropped from flight training due to repeated episodes of severe air sickness. Both students had a life long history of motion sickness. Other than the unusual history of motion sickness, medical examination revealed two young, healthy adult males, both highly motivated to remain in the flight program. By history and on the basis of their previous performance in the flight program, these two students demonstrated an incidence of air sickness far above average and one would expect a high susceptibility to motion sickness. This suspicion was confirmed in both studens where comprehensive vestibular testing revealed normal function with the exception of a very high susceptibility to motion sickness.

The rotating device used in this experiment is the Slow Rotation Room I (SRR) at the Naval Aerospace Reseach Laboratory in Pensacola, Florida. The experiment is conducted inside a windowless, air conditioned, circular room which is ten feet in diameter and seven feet high. This room is attached to a large, high mass centrifuge that is capable of very smooth rotation at angular velocities from one to thirty

revolutions per minute (rpm) (5).

By means of controlled vestibular stimulation each subject is well adapted to each increment of angular velocity. The rotation is provided by the SRR rotating at constant angular velocities. The vestibular stimulation consists of paced head movements. In this procedure the subject sits upright and upon command from a tape recorder he makes head movements to the left, right, forward and backwards. As shown in Figure 1, the angular displacement of the head movement is controlled by the placement of pads in each direction of the head movement at an angle of 45 degrees from the vertical. The subject moves his head in the desired direction until he lightly touches the appropriate pad. The commands from the tape recorder specify a given direction every four seconds with the command to return to the upright following the initial command by two seconds. With this arrangement, a discrete head movement is made every two seconds and at the end of 480 such head movements (16 minutes) the subject is given a three to five minute rest period during which he sits quietly with his head in the upright position. The incremental adaptation schedule will be designed on a daily basis by the authors with the objective of keeping the stress level as high as possible yet avoiding significant motion sickness. Measurements of the tumbling ("giant hand") illusion will be made at each new increment of angular velocity to estimate the intensity of the vestibular stimulation. The severity of motion sickness will be measured continually using a previously described grading system (2), which is summarized in Table 1. At the end of each daily rotation, head movements will be immediately conducted at zero velocity to assess the level of acquired direction specific adaptation. It has been proposed that the acquired adaptation which is not direction specific is continually overtaking yet always lagging behind the acquisition of direction specific adaptation (4). If a subject performs sufficient head movements at a given angular velocity, he can then continue his head movements at zero velocity without any incidence of motion sickness. This occurs, presumably, because he has continued his adaptation to the rotating environment for a period of time long enough to permit the decay of the more transient direction specific adaptation to occur, even as he is rotating. If the stress level is properly adjusted, the subject will display minimal illusions at each new increment in angular velocity and will transiently develop no more than one or two motion sickness points throughout rotation. At the conclusion of rotations the subject should remain essentially asymptomatic during the head movements at zero velocity. If the stress level is excessive the illusions will be more prominent, the motion sickness more severe, and the postrun head movements will elicit frank motion sickness. Each subject began at one rpm and worked his way to ten rpm as quickly as possible.

RESULTS

The first attempt at adaptation was conducted with Subject 1, whose motion sickness susceptibility was somewhat lower than that of Subject 2. These results are displayed in Table 2. This first experiment was conducted over a seven day period and involved rotation on six days. Rotation was always in the counterclockwise (CCW) direction.

On the first day Subject 1 reached 5 rpm and experienced no motion sickness throughout the day. The subject executed a total of 7200 discrete head movements. This corresponds to exactly 4.0 hours making head movements and was accomplished in 6.18 hours of rotation. Illusions were not prominent at each new increment in angular velocity. Due to a technical oversight, no postrun head movements were performed on this first day.

On the second day the subject reached 6 rpm and developed no more than 1 motion sickness point while rotating. He performed a total of 5760 head movements (3.2 hours) in 6.85 hours of rotation. Illusions were clearly present at first reaching 5 and 6 rpm. After stopping the subject developed 5 motion sickness points in 115 head movements.

On the third day the subject reached 8 rpm and displayed no more than 2 motion sickness points but remained at 1 point throughout most of the day. He performed 6240 head movements (3.47 hours) in 7.30 hours of rotation. Illusions were present but not prominent. During the postrun head movements the subject developed 6 motion sickness points in 90 head movements.

On the fourth day the subject did not exceed 8 rpm. He developed a maximum of 3 motion sickness points and displayed 2 points for much of the day. He performed 4320 head movements (2.4 hours) in 7.0 hours of rotation. Illusions were present but not prominent at 6-8 rpm. Upon stopping the subject developed 4 motion sickness points in 120 head movements.

On the fifth day the subject reached 10 rpm. He displayed a maximum of 2 motion sickness points at any time during rotation and was asymptomatic at 10 rpm. The subject executed a total of 6720 head movements (3.73 hours) in 8,05 hours of rotation. Illusions were detectable but not prominent. Upon stopping the subject developed only 2 motion sickness points in 120 head movements.

On the sixth day the subject spent most his time at 10 rpm. He displayed a maximum of 2 motion sickness points and was asymptomatic by the end of the day. The subject executed 3360 head movements (1.87 hours) in 4.57 hours of rotation. Illusions were present but not prominent. Upon the cessation of rotation the subject developed 3 motion sickness points in 120 head movements.

On the seventh and eighth days the subject was flown in an aircraft especially prepared for studying air sickness. The subject displayed normal susceptibility which was intrepreted as a significant improvement in his condition. Of the various maneuvers employed, the subject was most sensitive to "porpoising" which involved a few seconds of weightlessness. Several days later he participated in studies involving zero g parabolas of 30-45 seconds duration. Here he displayed such high air sickness susceptibility as to indicate that the incremental adaptation had afforded little protection for this particular type of maneuver.

Following the first incremental adaptation, periodic measurements of motion sickness susceptibility were made to estimate the rate of decay of the acquired adaptation. All of these tests were performed in the CCW direction, the same as that of the first incremental adaptation. At 12 days after the completion of the first study, there was minimal decay in the acquired adaptation. At 33 days there was significant decay and at 58 days the subject has returned to his previous baseline susceptibility.

Dissatisfaction with the incidence of motion sickness in the first incremental adaptation led to the decision to attempt a second, similar experiment. The objective was to examine the effects of lowering the stress level of the incremental adaptation schedule so as to reduce the incidence of illusions and motion sickness while rotating. This in turn would hopefully reduce the incidence of motion sickness caused by the postrun head movements. In this design the daily head movements always started at 1 rpm. This second CCW incremental adaptation was started 80 days after the completion of the first.

On the first day Subject 1 reached 3 rpm and was essentially asymptomatic throughout the day. He performed 3840 head movements (2.13 hours) in 3.50 hours of rotation. Illusions were not noted. Upon the

cessation of rotation, the subject developed only 1 motion sickness point in 240 head movements.

On the second day the subject reached 4 rpm and briefly displayed 2 motion sickness points upon initially reaching 4 rpm. He performed 3240 head movements (1.8 hours) in 3.2 hours of rotation. Illusions were not detected. Upon stopping the subject remained asymptomatic through 240 head movements.

On the third day the subject reached 5 rpm and briefly displayed a single motion sickness point at 1 rpm. He performed 2760 head movements (1.53 hours) in 2.4 hours of rotation. Illusions were not reported. After stopping the subject remained asymptomatic during 240 head movements.

On the fourth day the subject reached 6 rpm. He remained essentially asymptomatic but transiently developed 2 motion sickness points after a momentary power failure. The subject executed 2760 head movements (1.53 hours) in 2.4 hours of rotation. Illusions were not reported. Upon stopping the subject developed a single motion sickness point in 240 head movements.

On the fifth day the subject reached 8 rpm. He was intermittently symptomatic, displaying one or two points for much of the day. The subject executed 4920 head movements (2.73 hours) in 3.95 hours of rotation. Illusions were not noted. Upon halting the subject developed 2 motion sickness points in 240 head movements.

On the sixth day the subject did not exceed 8 rpm and remained asymptomatic throughout rotation. He performed 2760 head movements (1.53 hours) in 2.5 hours of rotation. Illusions were not noted. Upon stopping the subject developed 3 motion sickness points in 240 head movements.

On the seventh day the subject reached 9 rpm and intermittently scored 2 motion sickness points on two occasions during the day. He performed 3240 head movements (1.8 hours) in 2.85 hours of rotation. Illusions were not noted. Upon the cessation of rotation the subject displayed 2 motion sickness points in 240 head movements.

On the eighth day the subject reached 10 rpm and he briefly displayed 2 motion sickness points upon initially 10 rpm. He performed 5760 head movements (3.2 hours) in 4.3 hours of rotation. Illusions were absent. Upon stopping the subject remained asymptomatic in 240 head movements.

Although the second incremental adaptation employed slightly fewer head movements than the first, the successful adaptation to 10 rpm was accomplished with less motion sickness and a much lower incidence of illusions. Provocative tests to assess motion sickness susceptibility (6) were conducted at 7 and 8 days after the completion of the second incremental adaptation. When compared to the earlier baselines before both adaptation experiments, there was a substantial reduction in motion sickness susceptibility. When this test was conducted in the direction opposite to that of both incremental adaptations, i.e. clockwise, there was no evidence of transfer of adaptation to the opposite direction. This result was surprising since some transfer was expected. To examine this possibility in more detail, it was decided to conduct a clockwise (CW) incremental adaptation.

Subject 1 started a CW incremental adaptation 14 days after the conclusion of the second CCW adaptation experiment. The technique was to be the same as the second CCW experiment and the goal would be 10 rpm CW.

On the first day the subject reached a surprising 6 rpm and displayed a maximum of 2 motion sickness points during the day. He performed 5760 head movements (3.2 hours) in 4.75 hours of rotation. Illusions were reported upon first reaching 5 rpm. Upon stopping the subject developed 2 motion sickness points in 240 head movements.

On the second day the subject reached 10 rpm. At one point he briefly developed 3 motion sickness points but was back to 1 point within an hour. He performed 5160 head movements (2.87 hours) in 4.45 hours of rotation. Illusions were not present. Upon stopping the subject developed 1 motion sickness point in 240 head movements. The subject's rapid progress to 10 rpm CW was most likely due to transferred adaptation from the second CCW experiment.

At this point the subject was returned to flight training but due to a recurrance of a chronic sinusitis, he did not immediately return to flying status. Because of some difficulty in controlling this chronic sinusitis, Subject 1 was temporarily suspended from flying. However the problem finally subsided and the subject finished flight training with little difficulty. He is presently in an operational flying billet and periodic follow-up has indicated no abnormal incidence of motion sickness. In the fall of 1975 Subject 1 briefly returned to Pensacola and it was possible to again measure his motion sickness susceptibility. At this time he displayed a typical (mild) endpoint at 17 rpm which is well above the average of 7-8 rpm.

The incremental adaptation of Subject 2 consists of a single, lengthy adaptation to 10 rpm CCW. Some difficulty was anticipated in that Subject 2 was found to be one of the most motion sickness susceptible individuals ever tested at the Naval Aerospace Medical Research Laboratory. The plan was essentially the same as employed with Subject 1. The results of this experiment are displayed in Table 3.

On the first day Subject 2 reached 4 rpm in 0.25 rpm increments. He was symptomatic almost the entire day, averaging about 3 motion sickness points and once reaching 8 points. He executed 9120 head movements (5.07 hours) in 9.5 hours of rotation. Illusions were always present and prominent above 3.25 rpm. Upon halting the subject developed 12 motion sickness points in 240 head movements. Although the stress level was intentionally designed to be low, it was still excessive for this highly susceptible subject.

On the second day the subject did not exceed 2.5 rpm. The subject was symptomatic much of the time and averaged 2 motion sickness points. He performed 7680 head movements (4.27 hours) in 8.7 hours of rotation. Illusions were prominent above 1.75 rpm. Upon halting the subject developed 6 motion sickness points in 240 head movements. Again the stress level was excessive.

On the third day the subject did not exceed 1.75 rpm. Throughout the day he did not develop more than 1 motion sickness point. He performed 4320 head movements (2.4 hours) in 3.25 hours of rotation. Illusions were less prominent than on the previous two days. Due to technical difficulties, postrun head movements were not conducted on this day.

In view of the unusually slow progress toward 10 rpm, it was decided to attempt the incremental adaptation with the use of an effective antimotion sickness drug, d-amphetamine sulfate (7,8).

On the fourth day the subject did not exceed 2 rpm. This run employed 10 mg d-amphetamine sulfate p.o. and the subject was asymptomatic throughout the day. He performed 5760 head movements (3.2 hours) in 5.4 hours of rotation. Illusions were present but not prominent. Upon stopping the subject remained asymptomatic in 240 head movements.

Using this technique the subject gradually worked his way to 7 rpm, reaching it on the sixteenth day. The subject generally averaged one or two motion sickness points however the trend was toward greater motion sickness at higher angular velocities. He performed approximately 4000-5000 head movements per day.

Illusions remained present and were occasionally prominent. Postrun head movements were associated with gradually increasing motion sickness scores, reaching 8 points on the sixteenth day. At this point the drug was combined with the technique of starting all daily head movements at 1 rpm.

From the seventeenth through the twenty-fourth day the subject gradually worked his way to 10 rpm. D-amphetamine sulfate and the technique of starting all daily head movements at 1 rpm were continued. The subject was continually symptomatic and averaged about 2 motion sickness points during each day. He performed about 3000 head movements per day. Illusions were almost always present but rarely prominent. The postrun head movements produced from 6-10 motion sickness points.

On the twenty-fifth day the subject again reached 10 rpm and no drug was employed for this run. The subject displayed only 1-2 motion sickness points throughout the day. He performed 1920 head movements (1.07 hours) in 2.4 hours of rotation. Illusions were present but not prominent at 10 rpm. Upon stopping the subject developed 7 motion sickness points in 180 head movements.

Subject 2 subsequently returned to flight training which he completed with no unusual difficulty with air sickness. He is presently in an operational flying billet and periodic follow-up has not revealed any abnormal incidence of air sickness.

DISCUSSION

On the basis of the results of this experimental probe and the reports of other investigators (10), it is altogether likely that the incremental adaptation to 10 rpm was beneficial to the two flight students. Firm conclusions are difficult to achieve with such a limited number of subjects. However, both subjects have long felt that the adaptation experiments were of considerable aid in completing their flight training. It is clear that established laboratory tests demonstrate that these two subjects were able to reduce their motion sickness susceptibility while associated with the Laboratory. The relationship between the reduced motion sickness susceptibility upon leaving the Laboratory and the subsequent success in flight training requires more careful examination.

If, for example, the same tests that were used to measure motion sickness susceptibility before and after adaptation could be continued through flight training, then one might gain some insight into the relationship between incremental adaptation and improved flight training performance. To obtain a better comparison, students with comparably high susceptibility might be paired, one receiving incremental adaptation and the other continuing in the flight program. It would also be useful to periodically measure the motion sickness susceptibility of normal students as they progress through training. It is probable that the motion sickness susceptibility of student aviators as a group decreases as they progress through training. This effect must be considered before estimating any improvement attributed to vestibular adaptation.

There are several aspects of the data which deserve additional comment. In the case of Subject 1, there was good transfer of laboratory acquired adaptation to flight maneuvers with the exception of those involving weightlessness. A possible explanation may lie in the fact that weightlessness exerts a major effect upon the otolith apparatus whereas the vestibular stimuli employed in the laboratory primarily condition the semicircular canals. Since one would not expect a conditioning process involving the canals to necessarily transfer to the otolith apparatus, it is then understandable that the incremental adaptation to 10 rpm afforded little protection against weightlessness.

After the second CCW incremental adaptation of Subject 1, a motion sickness susceptibility test failed to reveal any significant adaptation to the opposite direction. This was surprising in view of earlier work (9) which predicted substantial transfer. When a subsequent CW incremental adaptation was conducted, the rapidity of the subject's progress clearly implied considerable transfer from the previous adaptation in the opposite direction.The only explanation presently available is that this test was conducted prematurely, before the complete decay of the direction specific component of adaptation.

In the case of Subject 2, the facilitation of adaptation through the use of drugs represents an interesting possibility that requires further investigation. Whether d-amphetamine sulfate promotes adaptability by suppressing motion sickness cannot presently be proven. With Subject 2, the decision to employ a drug was largely based on the desire to continue the incremental adaptation. The initial response to the drug was significant but due to the subject's complaints of nervousness, the dosage was gradually lowered. What effect increased dosage would have had on the increased motion sickness symptomatology above 6 rpm is not known.

The practical value of incremental adaptation is that it provides a method of reducing air sickness susceptibility which, although time consuming, can be accomplished safely, simply, and inexpensively with a minimal investment in equipment. This method does not involve the elicitation of motion sickness. Although the data presented here were collected on a slowly rotating room, there is no reason why the technique could not be arranged to utilize a simple rotating chair.

From a theoretical viewpoint, incremental adaptation represents a flexible experimental technique for gaining insight into the process of vestibular adaptation. By regulating the direction of rotation, the angular velocity, and the number of head movements, the investigator can reliably generate a variety of vestibular stress levels that range from the subthreshold to those which are frankly provocative of motion sickness. The relationship between motion sickness and adaptation is not well understood. It has been reported that adaptation can occur without incurring significant motion sickness (3) and this has again been shown in these results. However very little is known about the circumstances promoting optimal adaptation. From existing data it seems probable that motion sickness is not a necessary element of adaptation. This still allows the possibility that motion sickness actually retards adaptation which would seem to explain the behavior of some student aviators. If this should be true then the present method of making decisions on the presence of early or mild motion sickness symptomatology may not prove to be very efficient. In the present design the presence or absence of the tumbling illusion was noted with the initial head movements at each new increment of angular velocity. Although this information can be generally related to the adaptation process it is not presently clear how it alone might be used to establish an incremental adaptation schedule.

In summary, two well motivated flight students with a life long history of motion sickness were referred to the Laboratory due to persistent air sickness of such severity as to jeopardize their continued participation in the flight program. By executing numerous paced head movements on a rotating room of gradually increasing velocity, both students substantially reduced their motion sickness susceptibility to the laboratory rotating environment. After developing an essentially asymptomatic tolerance to 10 rpm through the technique of incremental adaptation, they returned to the flight program. Both students com-

pleted flight training and are presently in operational flying billets where they have experienced no unusual incidence of motion sickness. In these two cases it was possible to employ a recently described adaptation to vestibular stimuli which permits the effective transfer of reduced motion sickness susceptibility from the laboratory rotating environment to an operational flight situation.

REFERENCES

1. Graybiel, A. Structural elements in the concept of motion sickness. Aerospace Med.40: 351-367, 1969.
2. Graybiel,A., C.D.Wood, E.F.Miller II, and D.B.Cramer. Diagnostic criteria for grading the severity of acute motion sickness. Aerospace Med.39: 453-455, 1968.
3. Graybiel, A., and C.D.Wood. Rapid vestibular adaptation in a rotating environment by means of controlled head movements. Aerospace Med.40: 638-643, 1969.
4. Graybiel, A., and J.Knepton. Direction-specific adaptation effects acquired in a slow rotation room. Aerospace Med.43: 1179-1189, 1972.
5. Hixon, W.C. Instrumentation for the Pensacola Centrifuge-Slow Rotation Room I Facility. NSAM-875. NASA R-37. Pensacola, Fla., Naval School of Aviation Medicine, 1963.
6. Kennedy, R.S., and A.Graybiel. The Dial Test: A standardized procedure for the experimental production of canal sickness symptomatology in a rotating environment. NSAM-930. NASA R-93. Pensacola, Fla., Naval School of Aviation Medicine, 1965.
7. Graybiel, A., C.D.Wood, J.Knepton, J.P.Hoche and G.F.Perkins. Human assay of antimotion sickness drugs. Aviat.Space Environ.Med.46(9): 1107-1118, 1975.
8. Wood, C.D., and A.Graybiel. Theory of antimotion sickness drug mechanisms. Aerospace Med.43: 249-252, 1972.
9. Reason, J.T., and A.Graybiel. Adaptation to Coriolis accelerations: its transfer to the opposite direction as a function of intervening activity at zero velocity. NAMI-1086. Pensacola, Fla., Naval Aerospace Medical Institute, 1969.
10. Dowd, P.J., and R.L. Cramer. Habituation transference in coriolis accelerations. Aerospace Med.38: 1103-1107, 1967.

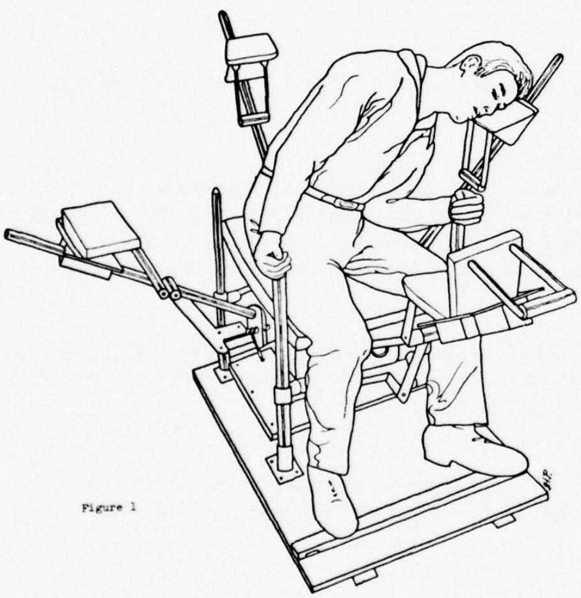


Figure 1

INCREMENTAL ADAPTATION — Subject 1

Date	Run Day	0	1	2	3	4	5	6	7	8	9	10	Daily Total	Average MS Score	Postrun HM	Postrun MS Score
8 Jan '71	1 (CCW)		0.96*	0.96	1.92	1.92	1.44						7.20	0		
9	2						1.92	3.84					5.76	1	0.12	5
10	3						0.48	0.96	3.84	0.96			6.24	1	0.09	6
11	4							0.48	0.96	2.88			4.32	2	0.12	4
13	5							0.48	0.48	0.48	3.84	1.44	6.72	1	0.12	2
14	6										0.96	2.40	3.36	1	0.12	3
			0.96	0.96	1.92	1.92	3.84	5.76	5.28	4.32	4.80	3.84			0.57	
													Grand Total: 34.17			
6 May '71	1 (CCW)		0.96	0.96	1.92								3.84	0	0.24	1
7	2		0.12	0.12	0.12	2.88							3.24	1	0.24	0
10	3		0.12	0.12	0.12	0.48	1.92						2.76	0	0.24	0
11	4		0.12	0.12	0.12	0.12	0.48	1.80					2.76	1	0.24	1
12	5		0.12	0.12	0.12	0.12	0.12	0.48	1.92	1.92			4.92	2	0.24	2
13	6		0.12	0.12	0.12	0.12	0.12	0.12	0.12	1.92			2.76	0	0.24	3
14	7		0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.48	1.92		3.24	1	0.24	2
17	8		0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.96	3.84	5.76	0	0.24	0
			1.80	1.80	2.76	3.96	2.88	2.64	2.28	4.44	2.88	3.84			1.92	
													Grand Total: 31.20			
1 June '71	1 (CW)		0.96	0.96	0.96	0.96	0.96	0.96					5.76	1	0.24	2
2	2		0.12	0.12	0.12	0.24	0.24	0.48	0.96	0.96	0.96	0.96	5.16	1	0.24	1
			1.08	1.08	1.08	1.20	1.20	1.44	0.96	0.96	0.96	0.96			0.48	
													Grand Total: 11.40			

Angular Velocity (rpm): columns 0–10

* 1.00 = 1000 individual head movements, spaced at two second intervals

Table 2

INCREMENTAL ADAPTATION — Subject 2

Date	Run Day	0	1	2	3	4	5	6	7	8	9	10	Daily Total	Average MS Score	Postrun HM	Postrun MS Score
31 Mar '71	1 (CCW)		1.92*	1.44	1.92	3.84							9.12	3	0.24	12
1 Apr	2		1.92	3.84	1.92								7.68	2	0.24	6
2	3		1.92	2.40									4.32	1		
3	4a		1.92	3.84									5.76	0	0.24	0
6	5a			2.88	0.96								3.84	0	0.24	0
7	6a			1.92	1.92								3.84	0	0.24	0
12	7b			0.96	2.88								3.84	0	0.24	2
13	8b				2.88	0.96							3.84	0	0.24	1
14	9b				0.96	2.88							3.84	0	0.24	1
15	10b					2.88	0.96						3.84	2	0.24	8
16	11b					1.92	1.92						3.84	0	0.24	1
19	12b					0.96	3.84						4.80	0	0.24	1
20	13b						1.92	2.88					4.80	1	0.24	5
21	14b							2.88	1.92				4.80	1	0.24	2
22	15c							0.48	0.48				0.96	4		
27	16b			0.48			0.48		2.88				3.84	2	0.24	7
28	17b		0.12	0.12	0.12	0.12	0.12	0.12	1.68	2.88			5.28	2	0.24	8
29	18b		0.12	0.12	0.12	0.12	0.12	0.24	0.48	[illegible]	0.96		3.48	2	0.24	7
3 May	19b		0.12	0.12	0.12	0.12	0.24	0.24	0.72	0.48	1.44		3.60	4	0.24	6
4	20b		0.12	0.12	0.12	0.12	0.24	0.24	0.24	0.48	2.16		3.84	3	0.30	10
5	21c		0.12	0.12	0.12	0.12	0.24	0.24	0.24	0.48	1.20		2.88	2	0.08	6
6	22c		0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.36	0.96	2.28	2	0.21	6
7	23b		0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.36	1.20	2.52	3	0.20	7
10	24c			0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.24	2.40	3.48	2	0.23	9
11	25		0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.24	0.72	1.92	1	0.18	7
			8.64	18.84	14.52	14.52	10.56	7.80	9.12	8.00	6.96	5.28			5.00	
													Grand Total: 107.24			

Angular Velocity (rpm): columns 0–10

* 1.00 = 1000 individual head movements, spaced at two second intervals
a 10 mg d-amphetamine sulfate, orally
b 5 " " " "
c 2.5" " " "

Table 3

Scoring Severity of Acute Motion Sickness

Category	16 points	8 points	4 points	2 points	1 point
Nausea syndrome	Vomiting or retching	Nausea* II, III	Nausea I	Epigastric discomfort	Epigastric awareness
Skin color		Pallor III	Pallor II	Pallor I	Flushing
Cold sweating		III	II	I	
Increased salivation		III	II	I	
Drowsiness		III	II	I	
Pain					Headache
Central nervous system					Dizziness: Eyes closed ≥ II; Eyes open III

*III = severe or marked, II = moderate, I = slight.

Table 1

This research was conducted under the sponsorship of the Bureau of Medicine and Surgery MR 041.01.01-0120 and the Office of Life Sciences, NASA, Johnson Space Center, Houston, Texas. Opinions and conclusions contained in this report are those of the authors and do not necessarily reflect the views of endorsement of the Navy Department.

DISCUSSION

K.E.Klein: Obviously, in the Skylab program, selection and training with respect to space sickness was not very effective. Would you please comment on the possible reasons for this, and on the improvement to be made in the Spacelab program, as your lack of transfer in one of your subjects of your adaptation effect to weightlessness seems rather discouraging.

W.J.Oosterveld: We have to keep in mind two things:

(1) The US astronauts were not subjected to any vestibular adaptation program. On a voluntary basis, they did a little flying in small airplanes, which cannot compete with a well designed adaptation program. This can explain the fact that more than 50% of the Skylab astronauts became motion sick.

(2) A well designed adaptation program gives a protection to air sickness and seasickness. There is a transfer of adaptation from one force environment to another. There is no reason why this transfer will not concern space sickness too. The coverage cannot be expected to be full, however, it will at least give a diminishing of chances to suffer from this.

The results with the second subject were not discouraging. They have proved that there was a strong transfer of adaptation from the incremental adaptation schedule to the force environment in an airplane with the exclusion of direct effect of weightlessness. This means that besides an adaptation as described, the candidate astronaut needs training in parabolic flight too.

G.Perdriel: Que pensez-vous de l'intérêt de l'électronystagmographie (E.N.G.) et de la cupulométrie (seuil de sensation) pour apprécier l'aptitude d'un candidat au vol spatial?

W.J.Oosterveld: I think that neither electronystagmography, nor cupulometry would be of interest for selecting candidates for space flight.

M.P.Lansberg: The very nice experiments of Dr Oosterveld have, I feel, once again shown that motion sickness is an extremely elusive condition. His motion sick pilot adapted well but for the situation of weightlessness. Astronauts who were notoriously unsusceptible to motion sickness became space sick, and it has yet to be proved that an adaptation procedure for susceptibles that gave no protection for the weightlessness situation could prevent non-susceptible aspirant astronauts from becoming space sick.

Concerning the question by General Perdriel, I would like to say that cupulometry, for all the good it has done to labyrinthology, has nonetheless no function in motion sickness physiology and pathology. Neither its sensation nor its nystagmus response bears any correlation for motion sickness susceptibility.

K.E.Klein: There has been an imbalance in astronauts after returning to earth (after splash down). Could you comment on the possibility that this is more an effect of muscular dysfunction than an effect of vestibular dysfunction?

W.J.Oosterveld: This imbalance is based more on muscular dysfunction than on vestibular effects. The vestibular system will rapidly adapt to the force environment on returning to earth and this is not the case with the musculature, which needs more time.

Experimental Investigations on Motion Sickness Susceptibility

by

W. HOFFELT, ORR, GAF

German Air Force Institute of Aviation Medicine

Fürstenfeldbruck

SUMMARY

The sensory conflict theory formulated by REASON was experimentally examined with psychological and sensory-physiological methods in two groups differing in their resistence towards coriolis accelerations. In all tests applied both groups showed consistent behavioural differences which may be interpreted in the sense of the conflict theory.

INTRODUCTION

According to internationally conforming experiences ten to twenty percent of all student pilots become airsick in the course of their training and up to 5 % are eliminated because of air sickness. It is remarkable that these students mostly become sick during their first flying hours which are characterized by only slight angular or linear accelerations. It is therefore not surprising that with respect to the vestibular functions no consistent differences may be found between the sick and the non-sick students. The reactions of stationary subjects in simulators with visual simulation or the phenomenon of the pseudocoriolis effect suggest to look for the causes of kinetoses not only in vestibular functional characteristics.

REASON presents a theoretical framework holding two essentially perceptual factors responsible for the motion sickness susceptibility. The main assumptions of his neural mismatch hypothesis are as follows: *Motion sickness is a maladaptation phenomenon.* It is the consequence of a conflict between the prevailing sensory afferences and those expected on the basis of past experiences. It is essential that the actual sensory input contains information, normally perceived by the vestibular apparatus. The air sickness persists as long as the content of the(assumed) sensory store is not congruent with the incoming sensorial pattern. In this case of incongruency a mismatch signal is triggered. It is assumed that the severity of the kinetosis symptoms is proportional to the strength of this signal.

According to the theory intensity and duration of the mismatch signal depend on two factors, respectivity and adaptability. Because of certain perceptive characteristics, highly receptive persons will experience discrepancies between the *sensory influx* and *stored sensory experience* values more intensely than less or non-receptives. Therefore, receptives will in any case generate a stronger mismatch signal than non-receptives when encountering an atypical motion situation. The time-course of the mismatch signal is a function of the individual adaptability. The sooner the stored sensory experiences are brought to a level compatible with the changed stimulus conditions the sooner the signal will disappear.

REASON succeeded in quantifying the individual position in both factors. His publications induced us to examine his approach experimentally.

METHOD

40 male students who were paid for their cooperation were subdivided according to their resistance to coriolis accelerations into two groups of equal size called non-susceptibles (NS) and susceptibles (S) respectively. To ensure that by this dichotomization situation-independent differences in motion sickness susceptibility would be covered, the subjects were required to fill in the Motion Sickness Questionnaire(MSQ) (see Ref. 1). The obtained highly significant correlation coefficient of rho = -.58 between the total number of sustained head motions and the MSQ scores proves that the separation into both sub-groups is based on time-stable personality traits which are of importance for individual kinetosis susceptibility. In a series of tests an attempt was made at identifying the quality of these traits. In detail the following test procedures were applied:

Perceptual Style: In literature the dimension field-dependency versus field-independency is brought into relationship with the most diverse aspects of human behaviour, among others also with the tendency to become motion sick. Thus BARRETT and THORNTON (2) observed in a stationary simulator with visual simulation that all extremely field-independent subjects had to break off the experiments prematurely because of nausea. The concepts of perceptual style and receptivity possibly stand for identical psychological realities. Thus, it makes sense to trace back the higher sensitivity of receptives towards sensory conflicts to their perceptual style. In order to investigate this assumption we tested the subjects with the CF-test by THURSTONE.

Spiral After-Effect (SAE): In several studies REASON (3, 4) obtained significant differences between susceptibles and non-susceptibles in the slope of the plot: SAE persistence against logarithmic prior rotation. Susceptible individuals tended to react more intensely to increasing levels of stimulation than non-susceptible individuals. REASON (4) discusses this finding in context with receptivity differences "determined by the characteristic way, in which the central nervous system, as a whole, coded stimulus intensity". We tried to reproduce this finding important for the theory by means of an EXNER-spiral 90 cm in diameter being rotated at 70°/sec. The stimulus intervals were 15 sec, 30, 45, 60, 75 and 90 sec. They were given twice in permuted sequence. The subjects were asked to give notice as soon as they could not perceive the after-effect any longer.

Apparent Vertical: According to theory persons developing symptoms of kinetosis differ from persons remaining free of symptoms, particularly in their receptivity. We feel that the stability of

spatial orientation could be used to demonstrate the greater awareness of conflicting sensory cues postulated for the receptives. We checked this by investigating the displacement of the apparent vertical by a visual stimulus rotating about the line of sight of the observer and occupying his entire field of vision. We expected a greater displacement in the S-group than in the NS-group. As stimulus apparatus we used a horizontally mounted hollow hemisphere 60 cm in diameter. The inner walls were patterned at random. By means of a hand-operated wheel the subject controlled the position of a co-axially mounted disk having nine cm in diameter. The disk was divided into equal halves by a black line. The deviation of the line from the objective vertical could be read off by the examiner in degrees. After presetting the line to angles of 30, 45 and 60° at random, the subject was asked to readjust the line to the vertical. 24 adjustments were performed with the right hand rotating hemisphere. The rotating speed was 100°/sec. The head of the subject was fixated. Under these stimulus conditions he experiences a sensation of rotation around his X-axis in opposite direction. Simultaneously the line on the disk seems to move to the left. The attempt to adjust the line to the vertical will therefore result in an adjustment error in direction of rotation of the hemisphere. The amount of the error can be seen as an expression of spatial disorientation.

Tilt Sensation: If the subject sits on a rotating chair located in the center of a closed cylindrical drum whose inner walls are painted with alternating white and black stripes, more or less pronounced discrepancies between merely perceived and actual self-rotation may be provoked by different combinations of constant chair- and drum rotations. If it is true that receptives react stronger to sensory conflicts than non-receptives this will have to show up in the intensity of their respective tilt sensations when bending their heads. The subjects were therefore asked to bend their heads laterally in order to provoke coriolis and pseudocoriolis effects in the following situations:

1) Rotation of chair with illumination switched-on (CH/Li on).
   Triggering of conventional coriolis effects with visual control of self-movement.

2) Rotation of drum with illumination on (DR).
   A visually induced sensation of self-rotation is the basis of pseudocoriolis effects in the stationary subjects.

3) Rotation of chair with illumination switched off (Ch/Li off).
   Triggering of coriolis without visual motion control.

4) Mechanical docking of chair and drum (Dock).
   Triggering of coriolis during visually perceived stand-still.

5) Chair- and drum rotation in the same direction, whereby drum has twice the rotatory speed of the chair, thus overtaking it (Overt.).
   Triggering of coriolis effects during an apparent sensation of self-rotation opposite to the actual direction of chair rotation.

The speed of rotation was 15°/sec. The ratings of the tilt-sensations were based on a standard stimulus (method by STEVENS (5)).

Effects of Optokinetic and Rotatory Stimulations: The subjective and objective effects of optokinetic and rotatory stimulations were measured in the above mentioned device consisting of a rotating chair located in the centre of a closed cylindrical drum. In detail the following parameters were measured: The duration of visually induced motion sensation (circularvection CV) after cessation of stimulus, the optokinetic nystagmus OKN and the optokinetic after-nystagmus OKAN, the duration of postrotatory motion sensation and the duration of the postrotatory nystagmus.

The chair respectively the drum were constantly rotated at speeds of 15°/sec., 60°/sec., and 120°/sec. The speeds were given at random sequence. The device was accelerated at sub-threshold level. According to the conflict theory we expected intergroup differences in the effects following optokinetic stimulations but not in the effects following rotatory stimulation.

RESULTS

Perceptual Style: We computed a rank correlation between the CF-scores and the total number of coriolis accelerations sustained up to nausea. The direction of the relationship was in agreement with our expectations, i.e. subjects tolerating many head movements showed a tendency towards a low CF-score and vice versa. The coefficient, however, was low and not significant. The relationship between the Closure Flexibility scores and the MSQ-score proved to be closer. For the NS-group we obtained rho= .52 (> 2%) for the S-group rho= .13 (n.s.). Since for the total group (N=40) rho was .58 (>1%), it can be said that perceptual style and susceptibility have common properties as suspected. Our data, however, based on 40 subjects only will not allow further specifications of the quality of these properties.

Spiral After Effect: If the mean after-effects of the 10 highly susceptible subjects (lower quartile) are compared with the 10 very resistent subjects (upper quartile) of our sample, the susceptibles show consistently longer after-effects than the non-susceptibles. The differences are significant at the 15 sec, 45 sec and 90 sec stimulus intervals. They are more pronounced in the longer stimulus intervals than in the shorter ones.

Regression coefficients of the regression equation $Y = a+b \log X$ were computed for the after-effects of the lower and upper quartile, Y standing for the mean SAE persistence and X for the duration of stimulation. For the NS-group there was a b-value of b= 9.21, for the S-group a b-value of b= 16.77. Fig. 1 shows that the plot of mean after-effect persistence against logarithmic prior rotation can be represented by a straight line. Fig. 1 further indicates, that the essential difference between

the two groups lies primarily in the extent with which SAE increases as a function of prior stimulation. Since the correlation between the spiral slope and the MSQ with rho= .31 was also significant for the total group (N=40) a good agreement with the results by REASON can be stated. It seems to be true, that "receptivity differences were determined by the characteristic way in which the central nervous system, as a whole, coded stimulus intensity"(4, page B4-3). REASON could show that the differences are not the result of the sensibility of the different sensory organs. Since they show up throughout various sensory modalities their cause would have to lie in central functional characteristics.

Apparent Vertical: If one compares, to what extent the subjective vertical in the 10 most susceptible (Q 1) and in the 10 most resistent (Q 4) subjects will deviate from the objective vertical under the influence of an optokinetic rotatory stimulus in 24 adjustments, the susceptible group will show a somewhat greater mean deviation. The difference, however, is not significant. Similarly to the SAE the essential difference between the two groups seems to lie in the quality of their central stimulus processing. Fig. 2 shows the b-values of the function $Y = a + b \log X$, whereby Y represents the amount of deviation and X the number of trials. The respective b-values are b= -1.54 for NS and b= -6.38 for the susceptible group. Fig. 2 indicates that the susceptibles are initially disturbed in their spatial orientation to a much higher degree by an optokinetic stimulus excluding all stationary spatial references than the non-susceptibles. Moreover, Fig. 2 shows that the difference between both groups diminishes with the duration of test. Subsumption of these results under the conflict theory is not readily possible. There is no doubt that the initially greater deviations in the group of susceptibles conform to expectations. The susceptibles experience a stronger sensory conflict and their spatial orientation is more impaired than in the non-susceptibles. What, however, could serve as an explanation for the relatively stronger decrease of the adjustment error in the susceptibles?

Since there is no reason to assume that the susceptibles are quicker in their adaptation to the rearranged sensory input than the non-susceptibles, they must regain their spatial orientation by other means. In this context we could think of a central suppression of disturbing informations, as it continuously occurs in human perception. It could also be possibly attributed to the success of a short-term reorganization of perceptive habits.

Tilt Sensations: The tilt sensation were provoked by lateral bending of the head in 5 situations in which the visual motion information conveyed a more or less appropriate impression of the actual rotation. Fig. 3 shows the increase of tilt sensations relative to the situation of the chair rotation with lights on. We related all ratings to the statements made in this situation because in our opinion it was only in this situation that there was no contradictory motion information. It is only in this situation that the visual input will produce an adequate impression of actual motion. The mean ratings substantiate these assumptions. The respective mean values for the NS and S are M_{NS}= 3.55; M_S= 3.60. Thus they are not only almost identical but also represent the lowest of all ratings. With increasing discrepancies between visual and vestibular afferences the ratings of both groups, however, show an increasing tendency of deviating from each other. The deviations are at their maximum in the overtaking situation, in which a rotatory impression had been provoked opposite to the actual direction of rotation. It is also remarkable that even stronger tilt sensations are reported when the stationary subjects had the mere sensation of being rotated (situation DR) than when exposed to true rotation (Ch/Li on).

The results seem to be plausible on the basis of the conflict theory. They seem to verify the assumption that motion sickness susceptibility is linked to a group-specific way of coding sensory inputs and processing inconsistencies between informations from the spatial senses. Because of their greater awareness of conflicting sensory inputs susceptibles tend to be more impaired in their spatial orientation than resistent persons. We feel that the magnitude of the tilt sensation is proportional to the extent of the disorientation.

Effects of optokinetic and rotatory stimulations:

a) After-Effect of CV: After switching off the drum illumination, positive and negative after-effects may occur. The positive after-effects are mostly attributed to nervous irritation still present after termination of stimulus. The negative after-effect is seen as a central counter-regulation. Thus, the duration of the positive after-effect is a function of both the nervous irritation and the counter-acting damping of irritation. Tab. 1 shows the results for the NS and S group.

Tab. 1 CV After-Effect in NS and S Subjects

		NS	S
Positive After-Effect	M	26.10	44.42
	s	23.61	56.58
Positive Plus Negative After-Effect	M	57.60	91.68
	s	41.50	87.13

Since F-tests are already significant for the positive as well as for the positive plus negative after-effects, the zero-hypothesis can be refuted at this level already. The differences in mean values indicate that the positive after-effect in the susceptibles recedes slower than in the non-susceptibles. This is even more noteworthy since the mean values for the negative after effect is also higher for the susceptibles. It may be assumed that susceptibles require a stronger central counter-regulation for damping their optokinetically induced irritation than the non-susceptibles.

b) Postrotatory Motion Sensation: The visually induced CV is the result of optical and vestibular afferences (6). The extent of the CV after-duration can thus also be traced back theoretically to vestibular excitation. To clarify whether there are also intergroup differences in the vestibular after-effects, we compared the duration of the post-rotatory motion sensation after abrupt decelerations from rotational speeds of 15°/sec, 60°/sec and 120°/sec with each other. Tab. 2 shows the results.

Tab. 2 The Duration of Post-Rotatory Motion Sensation in Non-Susceptibles and Susceptibles for Three Speeds of Rotation

		NS	S
15°/sec	M	19.05	19.16
	s	11.10	10.42
60°/sec	M	27.25	30.05
	s	11,11	10.53
120°/sec	M	31.70	30.78
	s	8.55	9.75

The similarity of the mean values in both groups was astonishing. The after-effects of different duration after optokinetic stimulation are likely to be caused by differences in the processing of visual motion information. The results in connection with the SAE and with the subjective vertical support this assumption.

c) Optokinetic Nystagmus OKN: As a result of our measurements with the 15°/sec, 60°/sec, and 120°/sec stimulus speed it was found that non-susceptibles react consistently different to an optokinetic stimulus than susceptibles. In the former we observed many eye movements with small amplitude and high speed, in the latter during the same time of measurement amounting to 30 sec. less eye movements with greater amplitudes and lower speed. These differences are significant for the total number of eye movements and for the magnitude of the amplitude throughout all three test speeds. As for the mean angular velocity of the OKN there was a significant difference at 120°/sec.

Concerning the implications of these findings for the individual susceptibility to motion sickness we can only resort to speculations. Possibly the tendentially lower speed of eye movements in susceptibles is an important detail. Eye movements which are slower than the stimulus speed result in an overestimation of the perceived movement of the object. It is likely that the group differences found after visual stimulation point to a physiological cause for the inter-individual differences in motion sickness susceptibility.

d) Optokinetic After-Nystagmus OKAN: The OKAN parameters revealed the same tendencies as those of the OKN, however, the group differences were not significant in any case.

e) Post-Rotatory Nystagmus: Literature contains contradictory statements concerning significance of different nystagmus parameters for individual resistence respectively susceptibility to kinetosis. In 1955 VAN EGMONT & GROEN (7) obtained cupulograms of differently steep slopes for the duration of post-rotatory nystagmus in pilots and non-pilots.

We compared the mean values as well as the cupulograms of several parameters of the post-rotatory nystagmus (duration of post-rotatory nystagmus, speed of the slow phase, duration of after-sensation, amplitude and frequency).We found neither significant differences in mean values nor differences in the slopes of the cupulograms between the two groups. This is a further indication that differences in susceptibility to coriolis acceleration existing between the two groups are primarily a function of the manner of visual information reception and processing but not a function of the sensitivity of the vestibular apparatus.

In an effort to arrive at a more globular characterization of the group differences beyond the merely elementary assessment of individual behavioural differences, we performed a discriminating analysis. It was found that by means of only 7 variables the probability of correctly classifying the 40 subjects into a S- and a NS-group equaled 75%. 5 of these variables pertain to the manner in which motion information is centrally processed. (SAE after 45 seconds stimulation, b-value of apparent vertical, number of eye movements in OKN and OKAN at 60°/sec stimulus speed, total amplitude OKN at 120°/sec stimulus speed). Again this result indicates that susceptibility towards kinetosis can not be attributed to a hypersensitivity of the vestibular apparatus.
An average probability of correct classifications of 75% is without doubt an encouraging result, however, for selection purposes it is not yet sufficient. Further investigations are necessary. Above all it would be important to study the influence of our separation criterion on the magnitude of the result. Since we abstained from exposing every subject to coriolis accelerations up to the point of vomiting, it was in part a question of motivation to which degree of nausea the subject participated in the test. In addition we largely ignored the adaptability factors. As shown by REASON, individual susceptibility is a function of receptivity and adaptability as well. Taking this factor into account will positively influence the result.

Mean spiral after effect for the lower (S) and upper (NS) quartiles of sustained coriolis accelerations.

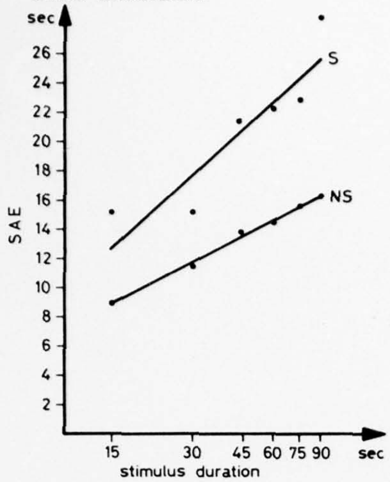


Fig. 1

The relative strength of tilt sensations (stimulus speed 15°/sec)

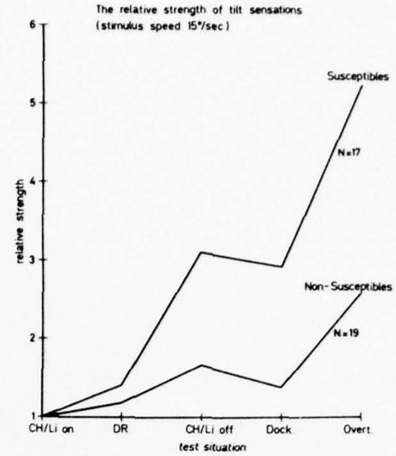


Fig. 3

Mean values for the displacement from the objective vertical for the lower (S) and upper (NS) quartiles of sustained coriolis accelerations.

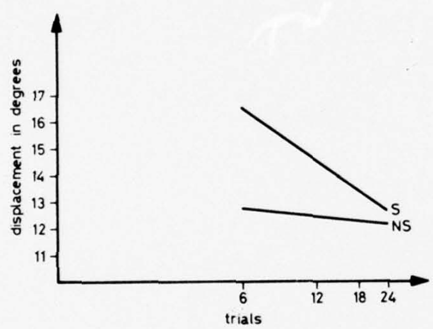


Fig. 2

1. REASON, J.T.: An Investigation of Some Factors Contributing to Individual Variation in Motion Sickness Susceptibility. FPRC/1277, 1968
2. BARRETT, G.V. & THORNTON, C.L.: Relationship Between Perceptual Style and Simulator Sickness. J. appl. Psych. 52/304-308, 1968
3. REASON, J.T.: Individual Differences in After-Effects of Apparent Motion, Part III: Spiral After-Effect Persistence, Estimations of Loudness, Motion Sickness Susceptibility. FPRC/Memo 226(c), 1966
4. REASON, J.T.: Factors Contributing to Motion Sickness Susceptibility: Adaptability and Receptivity. AGARD - CP - 109, 1972
5. STEVENS, S.S.: Direct Estimations of Sensory Magnitude. Amer.J.Psychol. 46/1-125, 1956
6. DICHGANS, J. & BRANDT, Th.: Optokinetic Motion Sickness and Pseudocoriolis Effects Induced by Moving Visual Stimuli. Acta Otolaryng. 76 339-348, 1973
7. EGMONT, A.A.J. & VAN GROEN, J.J.: Cupulometrie. Pract.oto-rhino-laryng. 17/206-223, 1955

SPACE MISSION SIMULATION - A NECESSARY ELEMENT IN PLANNING AND TRAINING FOR SHUTTLE SPACELAB MISSIONS

by
Lt. Col. Eduard C. Burchard, GAF, MC
GAF Institute of Aviation Medicine
808 Fuerstenfeldbruck
West-Germany

SUMMARY

The great achievements of manned space flight must be partly attributed to the tremendous effort made in preflight training of the crew. In an attempt during the last 2 years to evaluate space mission simulations, two Shuttle Spacelab Simulations were performed by the Life Sciences Directorate at the NASA Lyndon B. Johnson Space Center in Houston, Texas.

The First Spacelab Mission Simulation provided valuable insights into the many Shuttle Spacelab Operations which were not necessarily payload dependent. Two crewmen, free of Orbiter duties, acted as mission specialist and payload specialist to operate 12 typical life sciences experiments on a one shift schedule.

The Second Spacelab Mission Simulation involved one mission specialist and two payload specialists in a 7-day multidiscipline simulation which included 20 life sciences experiments and one cosmic ray laboratory experiment.

The use of space mission simulations in preparation for Shuttle Spacelab Missions are discussed.

The great achievements in manned space flight by the U.S.A. and the U.S.S.R. were - not regarding the technical and engineering aspects - made possible by the extensive, time consuming training and simulation efforts by the involved astronauts and training personnel. Crew training summaries of the 84-day Skylab-4 Mission and of the joint US-USSR Apollo/Soyuz Test Project (ASTP) Mission give an insight into the thousands of training hours spent in preparation for an actual flight (table I and table II). In order for the astronauts to complete 40 hours of actual training, it was necessary to allot a total of more than 80 hours for training due to the amount of time used by necessary activities such as traveling, eating, or dressing for spacesuit training. The most efficient use of time accomplished during the Apollo preflight training activities was a total of 42 hours of actual crew training within a 6 days per week training program. The use of simulators assumed a major role within the total training program. In many cases, the actual use of simulators surpassed preplanned training time by twenty to fifty percent or more. The Apollo and Skylab Eras came to an end with the ASTP Mission and left us facing a new manned space-system with totally different requirements for preflight crew training operations.

In the 1980's a whole new era of transportation will come into being with the event of the Space Shuttle and its ability to inexpensively transport a great variety of payloads into orbit. It is designed to reduce the cost and increase the effectiveness of using space for commercial, scientific, and defense purposes. With its versatility and reuseability the Space Shuttle will truly open the door to a very economical and routine use of outer space. Often in the history of manned space flight, man-machine relationships in space have proven to be highly effective; and in this respect the Space Shuttle is being designed and built to take advantage of the most efficient characteristics of both humans and machines. It is also the first time in the history of manned space flight that a space vehicle will be providing accommodations for up to seven space travelers.

The primary design and operation goal of the Space Shuttle Program is to provide low cost transportation to and from earth orbit. The Spacelab will be used considerably within the Shuttle system in support of manned orbital operations for scientific experiments.

On a standard mission the Orbiter can remain in orbit for 7 days, return to earth with personnel and payload, land like a gliding aircraft, and be ready for the next flight in 14 days. Within 24 hours after notification the Shuttle can be readied for a rescue mission and launched from a standby status. In this case the cabin can accommodate as many as 10 people.

The crew will be occupying a two-level cabin in the forward end of the Orbiter. Launch, orbital maneuvering, atmospheric entry, and landing phases of the mission will be controlled from the upper level flight deck. Seating for payload specialists, the scientists who perform the experiments in space, and their living area are provided on the lower deck.

The mission profile will be for a standard 7-day mission which can be extended up to 30 days and which will be able to accommodate up to seven crewmembers including four scientists or payload specialists.

For the first time space will be opened to men and women who are not career astronauts and whose prime responsibility will be the performance of scientific tasks and experiments rather than the actual flying of a spacecraft. With this in mind we have to consider the most appropriate approach to prepare these non-astronaut space travelers in order to assure their very best performance during the actual mission. Since they lack the experience and background of years of exposure to spaceflight problems, we must utilize a very efficient plan for their preflight participation in comprehensive full-scale simulations in order to make their participation in space flight a complete success.

In an effort to evaluate space mission simulations, two Shuttle Spacelab Simulations were performed at the Lyndon B. Johnson Space Center in Houston, Texas during the last 2 years. In October 1974 a full-scale simulation of a Spacelab mission dedicated to life sciences was conducted using a payload of typical life sciences experiments from NASA Ames Research Center and NASA Johnson Space Center.

The first 7-day Spacelab Mission Simulation was designed to elucidate interfaces and define requirements of handling life sciences experiments for the training of the participating crew and for the coordination with the principal investigators. The simulation included all premission activities required by an integration center: inflight payloads related operations; crew habitability functions; ground support operations required from the payloads operation center; and the training of flight controllers, flight crew, and primary investigators.

The First Spacelab Mission Simulation provided a valuable insight into many Shuttle Spacelab operations which were not necessarily payload dependent. Two crewmen free of Orbiter duties acted as mission and payload specialists to operate 12 typical life sciences experiments on a 1-shift schedule. They were confined to the Spacelab and Orbiter habitability area for the duration of the test. The constraints imposed on crew function by living in the mockup made a more accurate assessment of crew work capacity and time allocation possible.

A ground control team had to perform all the Spacelab support functions required from the payloads operation center which included interfaces involving the primary investigators. A series of operational test requirements were evaluated to give a realistic perspective of payload operation control functions in orbit, Spacelab operations, Spacelab systems design, and facility requirements at the payload integration center.

The Spacelab mockup used for the First Spacelab Mission Simulation was of plywood construction and was conceptually similar to the ERNO proposed basic designs. Commercially available standard equipment racks were used for mounting experiment hardware. Four black and white TV cameras monitored activities inside the Spacelab mockup. For this first test the Orbiter habitability area was simulated with a travel trailer located in a partitioned area immediately adjacent to the Spacelab mockup. A bicycle ergometer was provided for crew exercise. A locker was used to pass those items which could not be stowed before the test started in and out of the simulator. The trailer was used by the crew for eating, sleeping, and personal hygiene. The payload operations center contained the consoles and other functional elements necessary for providing payload operational support.

Twelve experiments were selected from 32 proposals as representative of the seven major areas of life sciences space research.

Mission preparation focused on the flight crew training, the experiments/payloads development, and the experiment integration into the Spacelab mockup during 2 days of integrated systems testing and 4 days of simulated flight procedures and integrated training for the flight team and crew. An astronaut physician and a molecular biologist were chosen as crew for the First Spacelab Mission Simulation and assigned as mission specialist and payload specialist respectively. Crew training concepts were developed in an effort to reduce training time and to evaluate the proposed roles of the mission specialist and payload specialist.

More than 350 hours of experiment training was accomplished in the primary investigators' laboratories and the Spacelab mockup. Crew training began with an informal discussion of theory with the primary investigator followed by observation sessions during which the primary investigator executed the experiment in his own laboratory. Each crewman, using the experiment hardware in the principal investigator's laboratory, practiced the procedures until he could duplicate the principal investigator's techniques and experimental protocol to the required proficiency. The final integrated training was performed during the 4 days of practice runs preceding the simulation.

The two, discipline trained crewmen, the mission specialist (M.D.) and the payload specialist (Ph.D.), conducted full-time payload duties on a single 16-hour shift schedule during which they were confined to the Spacelab and Orbiter for the duration of the test. A typical day consisted of 14.5 hours of crew flight planned activities, 8 hours of sleep, and 1.5 hours of free time. Approximately 9.5 hours of the crew flight activities were planned for experiment operations.

The primary investigators consulted with the crew in real time on the science dedicated air-to-ground loop during periods of acquisition of signal (AOS). Thus, they were able to discuss experiment progress, data quality, and unusual observations which optimized the scientific return of the experiments.

As malfunctions occurred, procedures were developed, approved, and coordinated with the crew for execution at a convenient time. There was considerably more flexibility for the crew in investigating and repairing malfunctions than in previous spaceflight programs.

The flight plan called for an hour a day of physical training and exercise. For this purpose a bicycle ergometer was provided.

The experience from the First Spacelab Mission Simulation provided valuable insight into problems evolving during a Spacelab Mission. The mission specialist's report presented 127 lessons learned and included numerous recommendations for future operations.

For the limited number of experiments conducted during the simulation, the approximately 350 hours of formal training and experiment operations over a 4-month training period proved adequate to conduct the life sciences experiments. Postflight analysis of the training situation also showed that team training of the crew promoted teamwork in experiment operations, produced better cooperation with the primary investigator, and, furthermore, enhanced the collection and quality of the returned scientific data.

Experience with the primary investigators' crew training demonstrated the need for a users guide to asist the primary investigator in determining training requirements for his assigned crew. As typical of the proposed Spacelab Missions, the primary investigators were much more involved in the immediate activity of their own experiments. It showed that the primary investigators should take an active role in integrated mission simulations and that he requires formal indoctrination in the functions expected of him during training simulations and the actual mission. It is proposed that the primary investigator should spend at least several weeks at the payload operations center during the final experiment integration and mission simulation, and that he should be available during these integrated simulations to assess the impact of malfunctions and

possible flight plan changes.

The Second Spacelab Mission Simulation (SMS-II) was conducted at the NASA Johnson Space Center on January 26 - February 1, 1976. This test also conducted as a simulated 7-day multidiscipline Spacelab flight and was managed by the Life Sciences Directorate (table III). Compared with the first simulation, this test facility included mockups of the Spacelab, of the Orbiter mid-deck and aft flight deck, a flight control room, and a payload operations control center. During this simulation 20 life sciences experiments (table IV) were performed within the Spacelab module and the Orbiter mid-deck, and one cosmic ray laboratory experiment was performed on the Orbiter aft flight deck (figure 1), and 14 operational test requirements (OTR's, table V) were performed (figure 2).

This time the crew consisted of a mission specialist and two payload specialists. Again, the mission specialist was an astronaut physician (the same one who had participated in the First Spacelab Mission Simulation). The payload specialists were a cardiopulmonary physiologist and a nuclear chemist who had extensive knowledge of the cosmic ray experiment which was included in the simulation.

The conditions of the Second Spacelab Mission Simulation were much more stringent than the first. Every attempt was made to conduct the test as realistically as possible within the limitations and constraints of the facility. The training schedule for this simulation started 14 weeks before the actual simulation (table VI). The training activities took place within a wide variety of different areas (table VII) and involved a great number of personnel who were tasked with test control and science monitoring during the 7-day mission simulation (table VIII).

During the simulation the crew remained continuously in the mockup. And, there were no interruptions of test operations due to facility support equipment or experiment malfunctions. Malfunctions were handled in much the same manner as in an actual flight. The crew's activities were performed using a 2-shift schedule with two crewmen working the day shift while the life sciences experiments were conducted and there was some periodic monitoring of the cosmic ray experiment. The cosmic ray experiment was worked by the third crewman during the night shift. During an overlapping time period when all crewmen were awake, the cosmic ray experiment payload specialist performed most of the required housekeeping functions.

For the Second Spacelab Mission Simulation the fidelity of the simulation facility was greatly improved in comparison to the First Spacelab Mission Simulation. The addition of the Orbiter mid-deck and aft flight deck, and the upgrading of the Spacelab to very closely resemble the ERNO configuration were major factors that lead to a more realistic simulation. The Second Spacelab Mission Simulation was much more complicated than the first due to the two-shift operation of the Spacelab Mission Simulation and the multidiscipline tasks which included a nonlife sciences experiment - the cosmic ray experiment. A separate science monitoring room was added for the Second Spacelab Mission Simulation for use as a payload operations control center.

Because the crew remained within the confined area of the mockup during the entire time of the simulation, the further operational evaluation of the food system, of the waste collection system, the dry trash stowage system, etc., provided valuable information during the test. Also, during this Second Spacelab Mission Simulation there was an abundance of lessons learned because of the multishift operation, the three crewmen involved, and the restriction in working and living area and confinement to the Spacelab mockup which especially enabled us to evaluate the habitability restraints. For the majority of the life sciences experiments it seems that a single shift is preferred where circadian rhythm changes might affect the data.

In the preparation for a spaceflight the development of good crew experiment procedures is mandatory to ensure effective training before the actual flight. Real time television downlink is of great advantage for operational purposes as it gives the primary investigator a direct insight to the performance of his experiments and enables him to direct input into the procedures. One of the outstanding lessons was that without question integrated training is mandatory toward optimizing inflight operational efficiency especially when the payload complement contains many experiments that are operated in parallel or in a timeline sequence. The integrated training also contributes toward the psychological adjustment of the team members in getting to know and work with each other. It is essential to consider the amount of this type of training that is necessary for maximum efficiency in Spacelab flights.

Consideration will be given to adding a commander and pilot to the crew for future tests. This will enable the interfaces between the activities of the different crewmembers to surface. In addition to the Spacelab and Orbiter systems management functions, the commander and pilot could participate in the experiment operations by acting as subjects and by assisting the mission specialists and the payload specialists.

In future tests great consideration will also be given to the experiments designed with 0 g in mind. Both crew and equipment restraints could be added to simulate 0 g activity in the Spacelab Mission Simulations. Furthermore, there will be more attention given to the problem of handling fluids in 0 g.

As far as training of the crew and the test teams is concerned, it will be necessary to apply more rigid standards in order to use training time more efficiently and at the same time reasonably limit the amount of time spent in training. The new concept of the Shuttle Spacelab Mission necessitates a change in the philosophy of the performance training of the respective crewmen. In previous missions up to Skylab, the training was done by NASA or NASA contractor instructors. During Skylab there was a shift to having some of the training done by the primary investigator. For the future Shuttle operations we expect that the primary investigator will do most of the experiment training himself.

While training in the laboratory of the primary investigator is, of course, necessary to prepare the payload specialist, it is in no way sufficient for providing the payload specialist with the necessary experience to perform his experiments in the closed environment of the Spacelab and/or Orbiter. During the latter part of the training the experiment hardware has to be used just as it will be flown on the Shuttle and in the configuration and in connection with the other experiments in the restricted area of the Spacelab or Orbiter in order to provide enough insight into the interfaces between the different experiments being conducted at the same time by several crewmen. And this in turn is only possible in a space mission simulation where the total crew is restricted by the limitations of the Spacelab and Orbiter mockups and can

perform their experiments as if they were flying in space.

The development of good detailed experiment procedures is a necessity early in the crew training program. The space mission simulation experience will improve and update the procedures and will help to smooth out the activities during the actual space flight.

In addition to crew benefits, the restricted environment of the space mission simulations also familiarizes the primary investigators and the primary engineers with the inflight problems involved and the limitations of communication, the ad hoc changes of procedures, and the total manned spaceflight operation. The primary investigator will be expected to devote a great amount of time to the training of the individual payload specialist(s) and to be available throughout the length of the training period and actual flight.

All the possible problems that might occur during Shuttle Spacelab missions have not yet surfaced during mission simulations. Future simulations including mixed crews and long duration missions such as 2, 3, or 4-week missions will be necessary to provide guidelines for the most efficient training of the crews for the Shuttle Spacelab Missions of the 1980's.

Table I

SL-4 CREW TRAINING SUMMARY AS OF 17 NOV 73
PREPARED BY TRAINING OFFICE

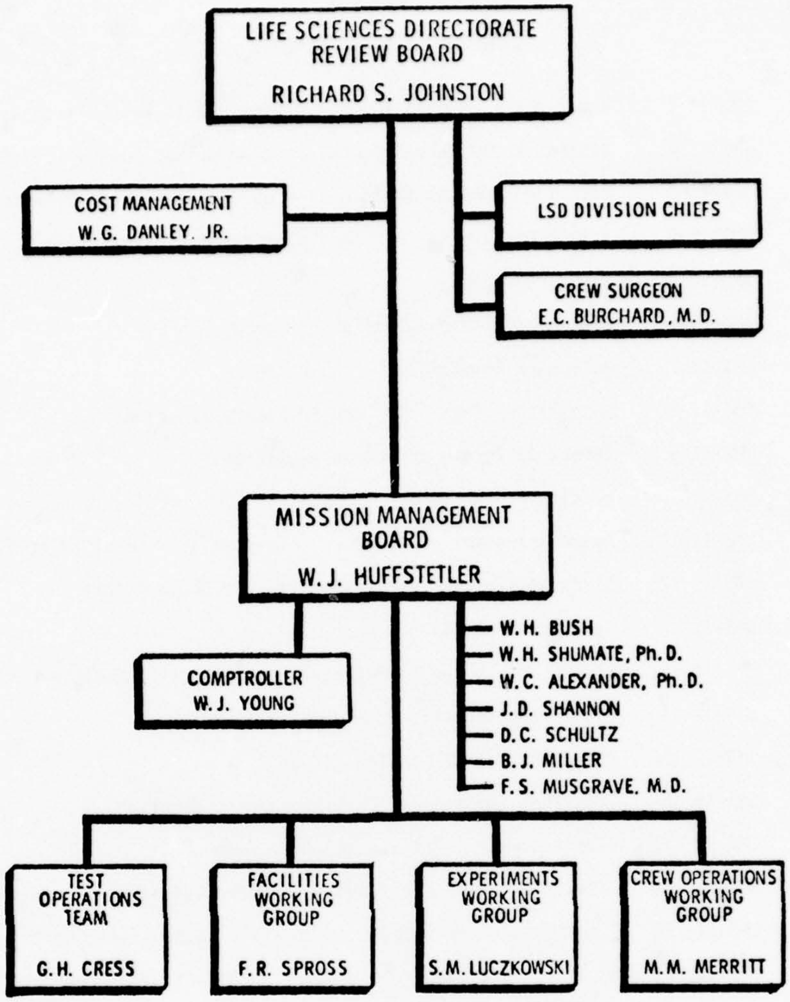
TRAINING ACTIVITIES	PLAN-NED (CDR)	HOURS ACCOMPLISHED *****CARR***** TOTAL	OCT-NOV	****GIBSON**** TOTAL	OCT-NOV	*****POGUE*** TOTAL	OCT-NOV
BRIEFINGS/REVIEWS							
CSM	95	74.5	0.0	74.5	0.0	68.5	0.0
OWS/AM/MDA/ATM	112	120.0	0.0	140.0	0.0	108.0	0.0
LAUNCH VEHICLE	8	6.0	0.0	6.0	0.0	6.0	0.0
SOLAR PHYSICS	110	164.5	12.0	182.0	13.5	150.0	12.0
FLT PLN/CHKLIST	75	86.0	8.5	100.0	8.5	99.0	9.5
MSN TECH/RULES	50	94.0	12.0	53.0	10.0	54.0	12.0
MSN SUPT (SL-3)	0	0.0	0.0	0.0	0.0	0.0	0.0
SYSTEMS TRAINING							
CREW SYSTEMS	46	90.9	6.0	73.2	3.5	97.7	13.0
TV	6	8.2	2.5	7.0	2.5	6.5	2.5
PHOTO	20	24.7	6.2	21.2	5.7	24.2	5.7
SWS ACT/DEACT	20	50.8	8.0	48.8	8.0	56.3	6.5
STOWAGE	28	17.0	7.0	17.5	5.0	18.5	6.0
EGRESS/FIRE	40	17.5	1.5	17.5	1.5	17.5	1.5
BENCH CHECKS	40	27.5	4.0	28.0	4.0	20.0	4.0
S/C TEST-MAND	50	123.5	3.0	123.5	3.0	201.5	3.0
S/C TEST-OPT	0	89.5	2.5	10.5	2.5	47.5	2.5
EVA/IVA							
WIF	42	39.0	9.0	84.0	9.0	39.0	9.0
ONE-G	119	63.5	3.5	63.0	3.5	64.5	3.5
ZERO-G A/C	0	0.0	0.0	0.0	0.0	0.0	0.0
MEDICAL	98	136.5	33.6	194.5	40.6	153.5	33.6
SIMULATORS							
CMS-BACKGROUND	0	128.0	0.0	113.5	0.0	134.0	0.0
CMS-SYLLABUS	300	515.7	58.2	474.6	48.8	466.0	46.4
CMPS	80	140.0	0.0	116.0	0.0	122.5	0.0
DCPS	15	33.5	0.0	36.5	0.0	12.5	0.0
SLS	300	355.6	24.1	415.2	40.1	430.8	24.7
OTHERS	0	200.1	9.0	256.8	9.0	234.7	9.0
EXPERIMENTS							
MEDICAL	98	105.3	5.2	154.2	4.0	125.0	1.5
EREP	72	125.2	12.0	77.7	9.0	159.9	14.5
ATM	46	47.5	2.5	68.0	7.0	43.0	2.5
COROLLARY	165	197.9	9.5	103.6	12.0	183.6	15.5
RESCUE	12	19.0	0.0	15.0	0.0	19.0	0.0
TOTAL HOURS	2047	3101.4	239.8	3075.3	250.7	3163.2	238.4

Table II

ASTP CREW TRAINING SUMMARY AS OF JUNE 30, 1975
PREPARED BY TRAINING OFFICE

TRAINING ACTIVITIES	PLANNED (CDR)	HOURS ACCOMPLISHED STAFFORD TOTAL	STAFFORD MONTH	BRAND TOTAL	BRAND MONTH	SLAYTON TOTAL	SLAYTON MONTH
BRIEFINGS/REVIEWS							
CSM	30	25.4	3.7	54.6	3.7	59.3	2.0
DM	20	8.0		21.5		24.9	
LAUNCH VEHICLE	5	2.6		3.0		2.6	
EXPERIMENTS	80	94.8	4.0	95.8	5.0	100.3	4.0
FLT PLN/CHKLIST	20	11.0	3.0	35.5	3.0	17.0	3.0
MSN TECH/RULES	30	26.5	2.0	58.0	2.0	20.5	2.0
SOYUZ	5	2.0		2.0		2.0	
SYSTEMS TRAINING							
TRANSFER PROCEDURES	20	17.5		27.0		17.5	
CREW SYSTEMS	20	17.5	1.0	24.0	2.5	22.0	5.0
TV	5	2.5		5.0		5.5	
PHOTO	10	11.0	2.0	11.0	2.0	9.5	2.0
EXPERIMENTS	70	74.3	22.0	76.0	19.0	110.0	22.0
STOWAGE	5	1.0		2.0		7.0	
BENCH CHECKS	10	12.0		12.0		12.0	
EGRESS/FIRE	10	13.0	2.0	13.0	2.0	13.0	2.0
S/C TEST	100	98.5	5.0	98.5	5.0	166.5	5.0
PLANETARIUM	-					12.5	
MEDICAL	20	31.0	16.0	19.0	12.0	29.0	13.0
SIMULATORS							
CMS/DMS	400	399.1	77.8	432.8	84.6	517.3	82.5
CMPS	25	32.5				56.0	
RUSSIAN LANGUAGE	900	968.0	41.5	906.5	28.0	1064.5	29.5
JOINT CREW ACTIVITIES	720	737.6	19.0	812.3	19.0	735.1	19.5
TOTAL HOURS	2505	2585.8	199.0	2709.5	187.8	3004.0	191.5

Table III



SMS-II Management Organization

Table IV

SMS-II

LIFE SCIENCES EXPERIMENTS

SMS-II 1	Hemodynamic Changes Following Exposure to Weightlessness
SMS-II 2	Central & Peripheral Hemodynamic Responses During Isometric Exercise
SMS-II 3	Effect of Orbital Fluid Shifts on Cardiovascular Dynamics
SMS-II 4	Effect of Zero-g Fluid Shifts on the Vectorcardiogram
SMS-II 5	Echocardiography
SMS-II 6	Hemopoietic Function of Bone Marrow
SMS-II 7	Pulmonary Blood Flow
SMS-II 8	Respiratory Physiology and Pulmonary Function
SMS-II 9	Effect of Zero-g on Thermoregulation
SMS-II 10	Vestibular Function
SMS-II 11	Acute Responses of Fluid and Electrolyte Metabolism to Space Flight
SMS-II 12	Study of Skeletal Muscle Function in Space Flight
SMS-II 13	Salivary Analysis
SMS-II 14	Effects of Zero-g on Muscle-like Contractile Proteins
SMS-II 21	Cosmic Ray Magnetic Spectrometer
SMS-II 15A	Determination of Cardiac Output
SMS-II 16A	Transient Analysis of Cardiopulmonary Function
SMS-II 17A	Biostereometric Analysis of Body Form
SMS-II 18A	Effects of Zero-g on Sporophore Formation of Edible Fungi
SMS-II 19A	Determination of Changes in Volatile Metabolites Due to Space Flight
SMS-II 20A	Specific Site Sampling in Spacelab Gas-Liquid Chromatography for Metabolic Contamination

Table V

SMS-II

OPERATIONAL TEST REQUIREMENTS

SMS-II 1-OTR	Medical Monitoring
SMS-II 2-OTR	Shuttle Medical Kit Definition/Review
SMS-II 3-OTR	Evaluation of CRT Hard Copy Device
SMS-II 4-OTR	Personal Hygiene Planning Concepts
SMS-II 5-OTR	General Housekeeping and Special Purpose Cleaning and Maintenance Concepts
SMS-II 6-OTR	Functional Utility of the Orbiter Mid-Deck
SMS-II 7-OTR	Waste Management Mockup
SMS-II 8-OTR	Shuttle Biowaste Monitoring System Evaluation
SMS-II 9-OTR	Potable Water System
SMS-II 10-OTR	Training Flow
SMS-II 11-OTR	Radiation Monitoring
SMS-II 12-OTR	Flight Planning Concepts
SMS-II 13-OTR	Shuttle Carry-on Concepts
SMS-II 14-OTR	Food System

Table VI

TRAINING SCHEDULE														
	WEEKS PRIOR TO TEST													
TRAINING ACTIVITY	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Test Team P.I. Briefings														
Test Team Experiment Demonstrations														
Crew Experiment Procedures Development														
Payload/Spacecraft Interface Briefings														
Experiment Documentation Reviews														
Experiment Flight Hardware Fam														
Crew (Less Pilot) Training Briefings & Exercises														
Pilot PI Briefings														
Pilot Training Exercises														
Experiment Objective Review (Team)														
Timeline Verifications (Team)														
Wet Runs On All Experiments														
Test Review and Safety Briefings														

Table VII

TRAINING ACTIVITY	RESPONSIBLE ORGANIZATION	CREWMEN				TEAM MEMBERS							
		PLT	MS	PS1	PS2	FD	PO	SYST	FAO	GR	SCIENCE	MO	SIM SUP
Initial PI Briefing For Team and Crew	LSD	16	16	32	32	16	32	16	16	16	16	16	16
Experiment Hardware Briefing For Team	LSD					8	8	8	8	8	8		
Experiment Procedure Briefing For Crew	LSD	4	10	40	40								40
Spacelab Systems Briefings	E&D	4	4	8	8	4	4	8	4	8	4		
Test Facility Hardware Briefings	LSD	2	2	2	2	2	2	2	2	2	2		2
Experiment Training Exercise	CTPD	90	90	262	262	32	64	16	16	2	32		
Stowage Briefing	E&D	2	2	2	2	2	2	2	2				
Safety Briefing	LSD	1	1	1	1	1	1	1	1	1	1	1	1
Emergency Egress Training Exercise	LSD	1	1	1	1								
Flight Plan Briefing and Reviews	CTPD	16	16	16	16	16	16	2	16	2	16		16
Malfunction Procedure Briefings	LSD	2	2	4	4	2	2	2	2	2	2		4
Mission Rules Review	FCD	4	4	4	4	4	4	4	4	4	4		4
Data Systems Briefing	LSD	2	2	2	2	2	2	2	2	2	2		
Wet Run	FCD	16	16	16	16	16	16	16	16	16	16	16	16
Total Hours		160	166	380	380	105	153	79	89	77	117	37	99

TRAINING ACTIVITY SUMMARY

Table VIII

Test Team Console Positions

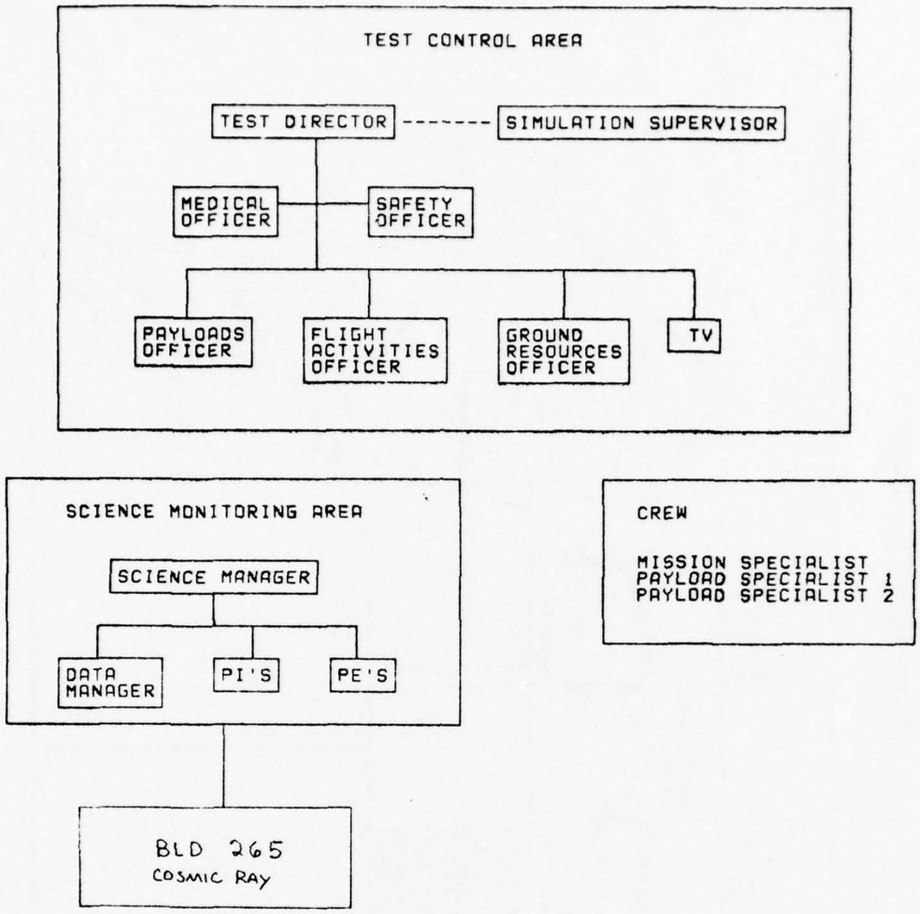


Figure 1

BASELINE AFT STATION CABINET CONFIGURATION - SC-103

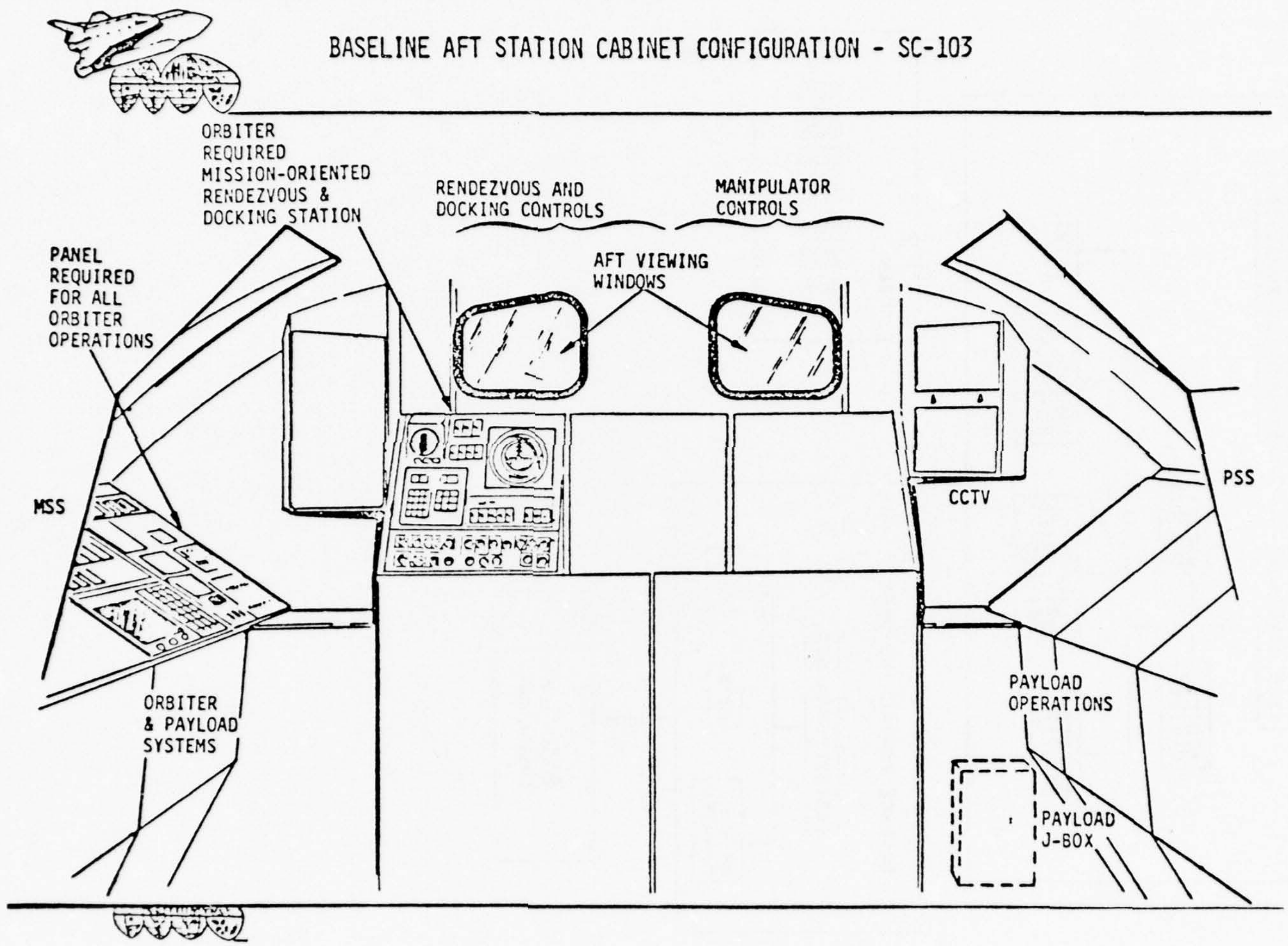
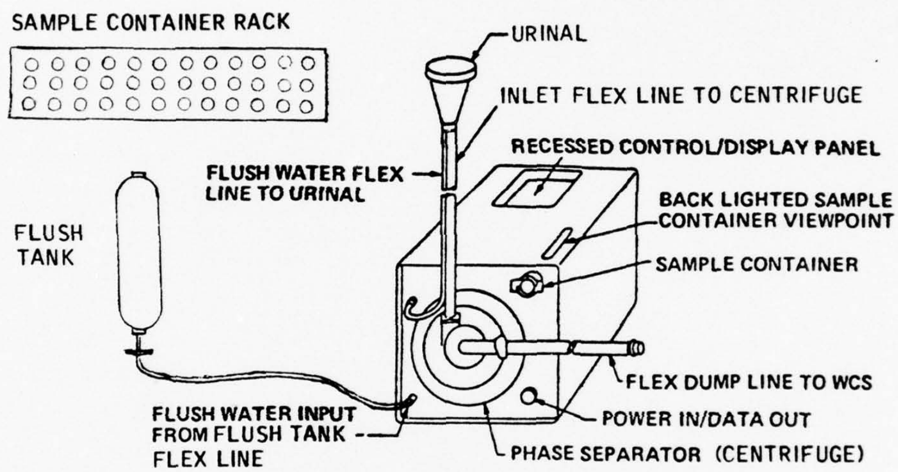


Figure 2

Example of an OTR: Biowaste Monitoring System

BMS ASSEMBLY



NEUTRAL BUOYANCY - ONE POSSIBLE TOOL FOR MAN'S TRAINING IN A SIMULATED ZERO-g-ENVIRONMENT

by

Heinz Oser, M.D.

Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt e.V.
Institut für Flugmedizin
5300 Bonn - Bad Godesberg
F.R. Germany

1. INTRODUCTION

Previous manned space flights have shown that man's adjustment to move and work in a zero-g-environment is very much relying on an intensive preflight training. Along with the new Shuttle/Spacelab Space program there will be also new requirements concerning the selection and training of the crew. First of all there will be three different types of crew members: the career-astronaut who will pilot and command the Shuttle/Orbiter; the mission specialist who will be responsible for the scientific payload and the Orbiter/Spacelab payload interfaces; and the payload specialist who will carry out the experiments within the Spacelab. The latter one will be an entire novice in spaceflights in contrast to the mission specialist and the career-astronaut who will be recruited from the professional astronaut staff members. Secondly, a part of the Shuttle philosophy is that scientists should have a chance to carry out their experiments in space with a minimum of preflight training. Here one cannot rule out that some of the selected scientists have never been exposed to an environment being different from that of their home and laboratory.

In order to get this last category of space crew members well prepared for performing their tasks under space conditions in a reasonable time, the water immersion technique for simulating certain aspects of zero and partial gravity condition is amongst others one possible tool. Zero-g-adjustment training will be of great importance for the Shuttle program since the flights will be of a rather short duration (7-28 days) and consequently only a very short time for inflight adjustment is allowable.

The water immersion technique has been used mainly for three purposes:
- studying physiological responses to weightlessness,
- evaluating human performance under quasi weightless conditions,
- testing equipment, facilities and simulation techniques.

Most of this work has been done in the years between 1959 and 1969 with a gradual shift in emphasis from biomedical to behavioural research (8).

In the first category aerospace medical researchers have used already 1942 the immersion technique as a research tool: they studied the acceleration protection of human subjects by submersing them in water (13).

This research tool began to broaden in scope by varying in the fields of interest like cardiovascular, respiratory or metabolic responses to immersion; and the results often left open whether the physiological changes were due to the simulated zero-g-environment or the used technique itself (2, 7, 9, 11, 12, 14, 28, 34).

However, in the second category in studies on spatial orientation, the method of just submerging a subject was considered to be sufficient to simulate weightlessness (2, 24). This holds true also for perceptual, cognitive and motor performance capabilities (15, 16, 17). Further studies established that the method of balanced gravity and, later, neutral buoyancy while being immersed in water, had to be applied in order to achieve a higher fidelity of the simulation: this method then allowed to carry out studies on the following topics: development and evaluation of techniques for manual locomotion (1, 22), body restraint as a function of task variables (3), manual force production capabilities under "weightless" conditions (23, 36), in-space-equipment-maintenance and -repair (23), and cargo transfer and restraint (21, 31). The good results which were gained by using the neutral buoyant technique for zero-g-simulation encouraged many authors to use this tool even for further investgations on spacecraft design and habitability problems: opening and shutting of hatches, travelling through hatches or crew transfer and through air-locks and passageways; finally, going as far as studying sleeping accommodation requirements. The results have proven the great value of the water immersion technique (1, 3, 6, 18, 19, 20, 26, 29, 32).

2. EQUIPMENT

Usually steel water tanks served as a training facility. Their size must be big enough to take up full scale mockups or workplaces. Enough depth should be provided in order to prevent an interaction of the test subjects with the bottom and surface. Several view observation ports below water level should allow external and adjustable platforms above water level direct operation observation. Consoles around the tank for the technical personnel, medical monitoring and the test conductor are of an essential nature. The water must be kept on a fairly high temperature (25°C-27°C) in order to conserve body heat during prolonged immersions, and on certain pH values.

Much attention should be paid to the water purity: usually it must be filtered and daily checked since micro-organisms can multiply at rates so high that water clarity cannot be maintained by even optimal filtering systems. In addition, small bubbles can be retained in the water surface tension, thus reducing clarity. In order to prevent these conditions, growth retardants, chemical treatment and frequent cleaning of the pool surfaces are necessary. Filming and TV-monitoring are as essential as two way communication systems and the monitoring of the subjects' vital signs and metabolic expenditures.

The diving equipment should include a hookah-gear for the subjects to be trained, SCUBA gear for the support divers, faceplate masks with communication units, various lead weight belts for the body and limbs; the hookah-gear will allow the subject a six-degrees-of-freedom within a normal center of mass range once neutral buoyancy is obtained. At least, the supervising personnel should be qualified divers.

Submerged full scale mockups of the space station or sections of it should be used for training purposes; moreover, the mockups and related hardware can be made also neutrally buoyant in order to simulate their reaction when being used or operated by the subject.

3. TASKS FOR TRAINING OF PAYLOAD SPECIALISTS

Since the subject is still gravity oriented, the water immersion does not allow a simulation of the "internal" physiological effects of weightlessness on subject performance. However, for certain task simulations requiring whole body movements like ingress-egress through passageways, the "internal" effects of weightlessness on subject performance can be neglected (30). For this class of task simulations the "external" effects of weightlessness, namely the lack of traction and support, become more important. These requirements will be covered fully by the water immersion method. Here three major classes of body movements can be selected:

- postural movements
- transport movements
- manipulative movements.

The postural movements are relatively large body motions required to regulate the orientation of the body in relation to some reference. In weightlessness, the gravity orientation cue is absent; consequently the postural movements will be made with reference to such external cues like inertial fields, visual references etc. Therefore, training tasks should use references in the simulation which allows the subject to orient himself: gravity is still present, producing a "normal" reference for orientation; additionally, visual aids and a vertical position, as the normal working or maneuvering position, can provide an acceptable reference frame.

The transport movements are characterized by moving the body through space. They are integrated with postural movements which function to modify and direct the transport movements. Training should take low-velocity and near-static tasks into consideration, where the movement is also of a short duration: an inadequate training task by using a relatively high linear velocity and long duration could lead to uncontrolled movements in weightlessness.

Both the postural and transport movements should be trained in tasks which are restricted to space and where force has to be applied: this would include ingress-egress through passageways, hatches and airlocks where the velocities are low and traction is available; torque application where body movement and position does not change rapidly, and emergency procedures.

The manipulative movements are those which involve the terminal elements of the body like the limbs, fingers or head. Movements in this category are not significantly affected by the water media in contrast to the previous mentioned ones. Typical tasks would include assembly, alignment, attachment of equipment where the drag forces on the body limb movements are relatively small, or the use of various body restraints, manual locomotion by hand rails, handholds and guiding lines.

Additionally, the underwater training leads to some more effects which can have a positive influence on payload specialist's preparation for space flights: they have to learn how to "live" and to move in an unusual environment, using a breathing apparatus for "survival" and being aware of working in a hazardous environment (35) with its impact to their motivation. Also, a body fluid shift towards the body center and head (2, 11) can lead to a habituation of the sensation which astronauts experienced during all their previous spaceflights. Moreover, underwater training has been even proposed as one tool of increasing a vestibular-autonomic stability by using various exercises like aerobatics (rotation in different planes and different types of figure swimming), using a compass for orientation by markers and the sun or underwater motion picture surveys (5). Also, investigations were made in a rotating water tank to determine the feasibility of the water immersion technique including an attempted elimination of the otolith cues by rotation (27).

4. DISCUSSION AND COMPARISON WITH OTHER ZERO-g-SIMULATION METHODS

Neutral buoyancy provides a total support of the body appendages with practically no change in the center of gravity, producing a six-degrees-of-freedom in all planes and axes. It is relatively non-time limited, and an entire set of procedures can be evaluated and trained without interruption. This technique is very useful for the training of many

intra- and extravehicular activities (IVA, EVA), and flight experiences have shown an excellent correlation between underwater training and actual performance of the same tasks under weightless conditions in orbit (30). The method allows to use flight type, full scale mockup configurations, as a whole or in sections, which also can be made neutrally buoyant.

The always present influence of gravity on the otolith has to be considered as one of the major disadvantages in this technique. There are also certain hydrodynamic factors which affect the underwater behaviour and motion of both the submerged subjects as well as the components like mockups etc. Hydrodynamic drag and mass effects on modules maneuvered or transferred by subjects under water were found to leave a significant impact on simulation fidelity (10). Drag effects on the subject were found to be negligible when tasks were performed at velocities of 2 ft per second or less, yet were rapidly influential above that velocity (25, 33). There are also handling problems with large mockups, tools and wiring and they all require some water proofing. Some visual problems are encountered by the face mask as well as by distortion from the refractionof light in the water. Attention should be paid also to the possible subject's skin maceration after frequent and long underwater exposures, but this can be kept in an aceeptable limit when personal hygiene provision, a physiological NaCl-content and pH-value of the water is given.

Other techniques than neutral buoyancy for simulating zero- or low-g-conditions include parabolic flights with aircrafts and multiple-degree-of-freedom simulators, using sling suspensions, gimbals and air bearings, either singly or in combination.

Flying parabolic trajectories is the only technique that produces for a short time "real weightlessness". It is suitable for obtaining quantitative measurements because operational parameters (e.g. action/reaction forces, operator body stability) can be identical to flight conditions. It is useful for determining unknown mass dynamics. Additionally, a subject also can experience the "internal" effects of zero-g like his body fluid shift towards the head or the various vestibular stimulations. The major disadvantages include very short periods of zero-g (up to 30 seconds) with immediate following high-g-periods (2-3 g) during the "pull-outs", causing also a high incidence of motion sickness; a weather-dependant scheduling, limited volume and interrupted training procedures are some other disadvantages.

The multiple-degree-of-freedom simulation techniques provide an approximation of the zero-g-environment. It is a useful tool for developing fixed position, standup or sit down workstations that require limited gross body movements and placing the subject in unusual attitudes. A rather complicated air bearing low-g-simulator provides a two-degree-of-freedom platform which can be used e.g. for mounting equipment for simulations in conjunction with a multiple-degree-of-freedom system for the subject. However, this simulator does not eliminate the psychosensory or physiological effect of gravity and the body motion is restricted by harness assembly. Several operational parameters differ from zero-g-conditions. Operator strength/package mass ratios are usually greater and task times are longer.

5. CONCLUDING REMARKS

According to the tremendous previous work, research and good results on using neutral buoyancy during water immersion it is reasonable to assume that this method serves as a useful zero-g-simulation technique for training unexperienced spaceflight crews. The technique can also be extended to human performance research and spacecraft design verification. However, training of the crew in particular should be done in a balanced program involving also parabolic flights with aircrafts and other partial simulations of the weightless environment.

REFERENCES

1. Adams, C.R., and G.K. Bulk.: Zero buoyancy-simulation of weightlessness to evaluate psychophysiological and anthropometric parameters that affect space station design. Aerosp.Med. 38, 1967, 518-520.

2. Benson, V.G. et al.: Weightlessness simulation by total body immersion; physiological effects. 1961. Johnsville, Pa.: US Naval Air Development Center, Rept. No. NADCMA, 6134.

3. Bulk, G.K., and C.R. Adams: An empirical study of devices and techniques to improve the astronaut's performance in an orbital space environment. 1964. Douglas Aircraft Co., Rept. No. 3035.

4. Campbell, P.A., and S.I. Gerathewohl: The present status of the problems of weightlessness. Tex.State Journal of Medicine 55, 1959, 267-274.

5. Chirkov, A.A., L.N. Kornilova, and S.N. Markov: Underwater training as one of the factors increasing vestibular-autonomic stability. Current Problems in Space Biology and Medicine (Moscow), 1971, 286-287.

6. Dean, R.D., and R.P. Langen: Simulated weightlessness under neutral buoyancy. Proceedings, Interdisciplinary Symposium on Apollo Applications Program, Huntsville,Ala., 1966. NASA-MSFC.

7. Diringshofen, H.von: Immersion in water as a partial simulator of weightlessness in space medicine. Archiv f. Physikal. Therapie 14, 1962, 3o7-311.

8. Duddy, J.H.: The simulation of weightlessness using water immersion techniques: An annotated bibliography. Human Factors.11 (5), 1969, 5o7-54o.

9. Gauer, O.H.: Physiological problems of weightlessness and basic research. Paper presented at the 1 st Int.Symp. on basic problems of man in space. Paris,Oct. 1962.

1o. Goldstein, S.E. and U.R. Alvarado: A method for obtaining high-fidelity underwater simulation of manned space activities. Paper presented at the AIAA-Annual Meeting, Anaheim, Calif., Oct. 1967.

11. Graveline, E.E. and B. Balke: The physiologic effects of hypodynamics induced by water immersion. 196o. Brooks AFB, Rept. No. 6o-88.

12. Graveline, D.E. and G.W. Barnard: Physiologic effects of a hypodynamic environment, short term studies. Aerosp.Med. 32, 1962, 726-736.

13. Gray,R.F. and M.G. Webb: High-gravity protection. 196o. Johnsville, Pa. U.S. Naval Air Development Center, Rept.No. NADCMA-5910.

14. Graybiel,A. and B.Clark: Symptoms resulting from prolonged immersion in water: The problem of zero-gravity asthenia. Aerosp.Med. 32, 1961, 181-196.

15. Hanna,T.D.: Psychomotor performance during total body water immersion for massed and spaced learning on a complex task. Aerosp.Med. 34, 1963, 256.

16. Hartman,B.: An exploratory study of changes in proficiency in a hypodynamic environment. 196o. Brooks AFB,Rept. No.6o-72.

17. Hauty,G.: Psychophysiological problems in space flight. In: Bioastronautics, K.E. Schaefer (Ed.). New York, Macmillan Co., 1964.

18. Loats, Jr.,H.L. and Mattingly: A study of the performance of an astronaut during ingress and egress maneuvers through airlocks and passageways, phase i. Wash.DC., 1964, NASA Rept. No,NASA-CR-6634o.

19. Loats, Jr., H.L. et al.: A study of the performance of an astronaut during ingress and egress maneuvers throgh airlocks and passageways, phase ii, vol. iii, appendices, Wash. D.C., 1965, NASA Rept. No. NASA - CR -66343.

2o. Loats, Jr. H.L. et al.: A study of the performance of an astronaut during ingress and egress maneuvers through airlocks and passageways, phase ii, vol. i, Wash.Dc., 1965, NASA Rept.No. NASA-CR-66341.

21. Loats,Jr., H.L. and Mattingly: Study of the astronauts capabilities to maintain life support systems and cabin habitability in weightless conditions. Mod. 3: A new technique for investigating cargo transfer in simulated weightlessenvironments. Wash. 1968. Wash.D.C., NASA Rpt.No.NASA-CR-667o8,1968.

22. Margaria,R. and G.A. Cabagna: Human locomotion in subgravity. Aerosp.Med. 35, 1964, 114o-1146.

23. Miller,E.S. et al.: Human engineering studies for maintenance and repair in zero-gravitiy. 1967. Philadelphia, Pa: General Electric, Rept. No. 67 SD-292.

24. Nelson,I.G.: Effect of water immersion and body position upon perception of the gravitational vertical. Aerosp. Med. 39, 1968, 8o6-811.

25. Pao, Y.C.: Mathematical model analysis of underwater simulation. 1966. Los Angeles, Calif.: Garrett Airesearch Manuf.Co., Rept. No.LS-66-o794.

26. Rasquin,I.R.: Underwater operation experiments evaluation. 1967. Huntsville, Ala. NASA-MSFC, Rept. No.NASA-TM-X 53614.

27. Stone,Jr., R.W. and W. Litko: Some observations during weightlessness simulation with subject immersed in a rotating water tank. 1964. NASA Rept. No.NASA-TN-D-2195.

28. Ting,E.Y. et al.: Lung volumes lung compliance and airway resistance during negative-pressure breathing. Journ. of appl. phys. 15, 196o, 55o-553.

29. Trout, Jr., O.F.: Water immersion technique for simulation of ingress-egress maneuvers under conditions of weightlessness. In: Selected papers on environmental and attitude control of manned spacecraft. NASA-LRC, 1966.

3o. Trout, Jr., O.F. and W.Bruchey: Water immersion reduced-gravity simulation. Human Factors 11, 1969, 473-488.

31. Trout,Jr., O.F. : Work performance in space. 3 rd NASA Ad Hoc Working Group Meeting on Extra-Vehicular Technology and In-Space Maintenance. NASA-ARC,1967.

32. Trout, Jr., O.F.: Investigation of man's extravehicular capabilities in space by water immersion simulation technique. Paper presented at AIAA-Meeting, Boston, 1966.

33. Trout, Jr., O.F.: A water immersion technique for the study of mobility of a pressure-suited subject under balanced gravity conditions. 1966. Langley Station, Va. NASA-LRC, Rept.No.NASA-RN-D-3o54.

34. Walawski,J.: Observation on heart rates and cardiodynamics during prolonged weightlessness simulated by immersion method. Paper presented at the 1 st Int. Symp. on Basic Environmental Problems of Man in Space. Paris, 1962.

35. Wolf, R.L. and W.A. Shafer: Safety, emergency and operating procedures for underwater testing. San Diego, Calif., 1966. General Dynamics Convair, Rept. No. GDC-ERR-AN-757,Rev.A.

36. Wortz,E.C. et al.: Study of astronaut capabilities to perform EVA maintenance and assembly functions under weightless conditions. 1964. Wash.D.C., NASA Rept. No.NASA-CR-859.

DISCUSSION

K.E.Klein: Have you any knowledge on the experience of astronauts with respect to the effectiveness of underwater training (neutral buoyancy)?

H.Oser: So far, EVA underwater trained tasks showed a very good correlation with the tasks being performed later in space. Even though the astronauts considered the work underwater harder, they said it was a very useful training because it made their work easier in space.

Henemann: How can you control the buoyancy of the diving subject since inhaling and exhaling is influencing the buoyancy once being submersed.

H.Oser: By applying lead weight belts to the limbs and extremities, very carefully placed. The subject then controls his breathing very quickly so he can be extremely well neutrally buoyant.

HUMAN ENGINEERING – CREW SYSTEMS TOOL FOR SPACELAB DESIGN

BY
Udo G. Munkelt, Ing. (Grad.)
Crew Systems Section Head
and
Harold S. Jencks – Consultant
Crew Systems McDonnell Douglas

ERNO Raumfahrttechnik GmbH
Huenefeldstr. 1–5
2800 Bremen / W. Germany

SUMMARY

Under the leadership of the European Space Agency (ESA), a EUROPEAN Consortium, headed by ERNO Raumfahrttechnik GmbH, Bremen, W. Germany, is developing and building Spacelab, a manned Space Laboratory.

Dominating Spacelab design is the need to accommodate scientific personnel performing a broad spectrum of experimental activities that will change considerably over the years. Thus the design emphasizes versatility for multipurpose use, capitalizing on man's adaptability and decision making capabilities.

As Spacelab crews generally will not be young, extensively trained astronauts as in the past space programmes, and the optimum usage of the relatively short time in space is mandatory, the consideration of human factors during Spacelab design/development becomes a particularly challenging factor, perhaps more so than in any previous manned spacecraft.

This paper briefly describes the Space Shuttle/Spacelab system with emphasis on crew accommodation/utilization. It discusses the artificially supplied internal environment which provides for the well being of the crew in the hostile surroundings of space including atmosphere, temperature, lighting and noise. It pesents the interior arrangement of Spacelab showing architectural considerations which essentially provide a one – G oriented concept in respect to work stations, display control consoles, floor, ceiling, etc., minimizing disorientation and facilitating ground operations. It describes the restraint systems provided which enables the crewman not only to overcome the negative aspects of working in zero – G, but also to take advantage of the positive aspects. Several photos and sketches are provided showing full scale Mockups and neutral buoyancy test fixtures which support the human engineering considerations in Spacelab design/development.

INTRODUCTION

With the advent of Spacelab, Europe's entry into the manned space era has begun. One of the unique and interesting aspects of designing an orbiting space station is taking into account the human engineering for man in the strange environment of weightlessness. Early manned flights such as Gemini and Apollo were not greatly involved with the free environment of man in zero – G, each having less than 3 cubic meters of usable volume per crew man. Skylab with its internal volume of approximately 340 cubic meters (100 times that of Gemini) and now Spacelab with approximately 25 cubic meters required addressing the need for mobility aids and restraints and concentrated design consideration for various habitability functions.

The Skylab programme provided considerable insight into man's capability to function in zero gravity. Generalizing, one can state that Skylab showed that if a crewman is given a satisfactory restraint system he can perform any task in zero – G that he can do in one – G – some even better.

Skylab designers used many methods to verify the human engineering design concepts: mockups, neutral buoyancy (under water) tests, KC 135 Keplerian trajectory zero – G flights, etc. Spacelab is using mockups, some neutral buoyancy tests, perspective drawings, and a great deal of Skylab experience carry over to support the crew habitability human engineering design activity.

SPACE SHUTTLE

Spacelab will be launched, maintained in orbit and returned to earth aboard the American Space Shuttle. The Shuttle is a reusable launch vehicle scheduled to be operational in the 1980 time period. Spacelab will remain in the Shuttle Orbiter Payload Bay for its entire mission of from 7 to 30 days. Figrure 1 shows one orbital configuration of Spacelab in the Orbiter payload bay with the Orbiter doors open. The Shuttle's function during a Spacelab mission is to place Spacelab into orbit, provide facilities for eating, waste management, sleeping, personal hygiene and other logistic support to the crewmen and a safe return home, while Spacelab is dedicated to perform as a zero – G manned space laboratory. The crew will consist of the commander, the pilot, the mission specialist, and up to four payload specialists. The mission specialist will be the principal onboard expert for both Orbiter and Spacelab basic subsystems and will monitor, control, activate, trouble shoot, maintain and deactivate these subsystems as required. He will also assist the payload specialists on a time available basis. The commander and the pilot will operate the Orbiter in support of the mission and will assist the mission specialists and payload specialists on a time available basis. Figure 2 shows a section through the flight deck of the Orbiter.

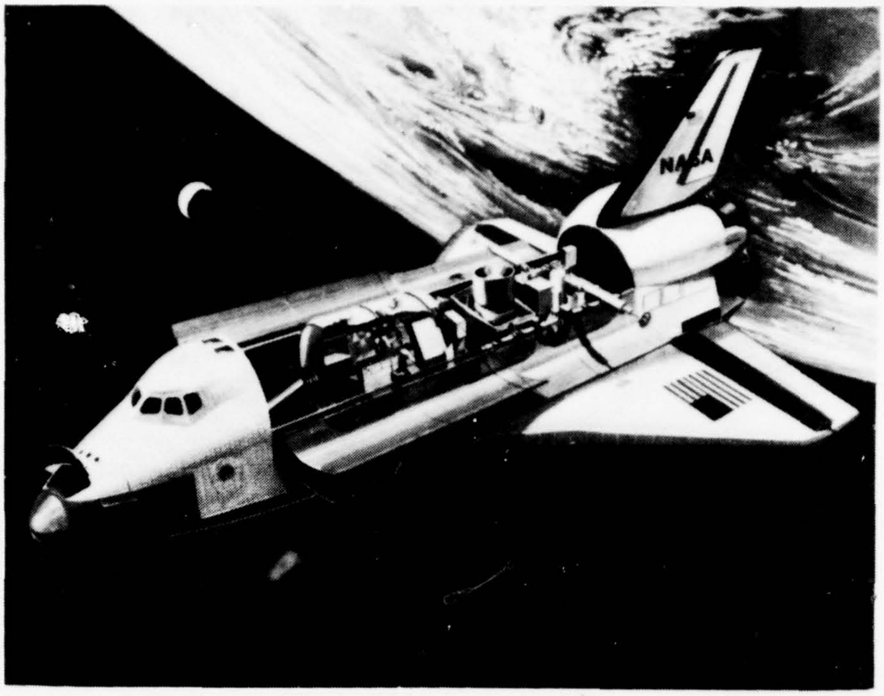


FIG.: 1 SPACELAB IN ORBITER

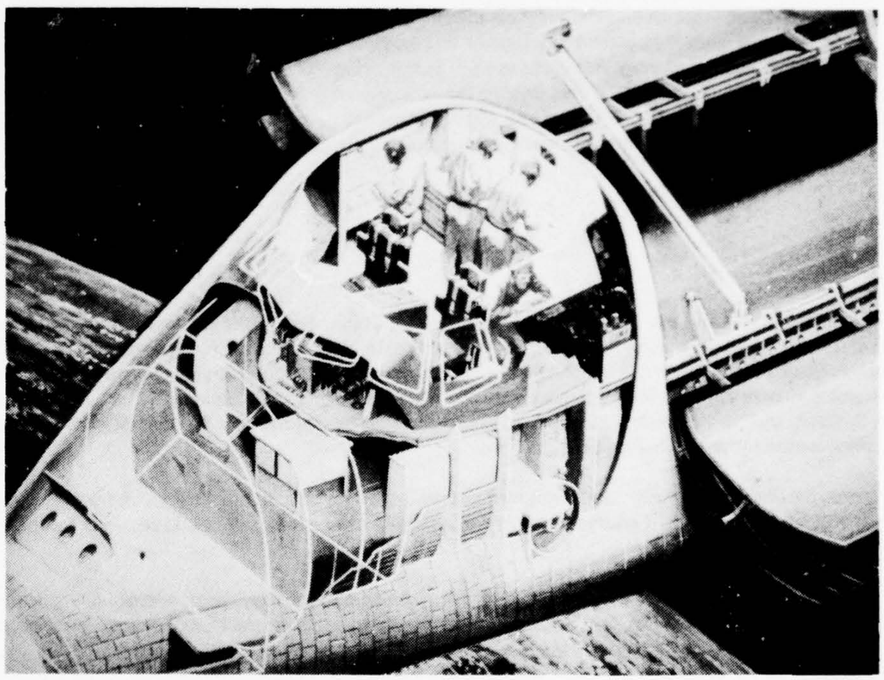


FIG.: 2 ORBITER FLIGHT DECKS

SPACELAB

Spacelab is in reality a term for a variety of possible configurations of pressurized modules and/or pallet combinations. This paper primarily deals with the pressurized double module, a cylinder roughly 4 m in diameter and 6 m long. The Spacelab is as its names implies, a space laboratory. Its primary purpose is to provide a workshop in which scientists may carry out experiments. The nominal Spacelab mission lasts 7 days. Launch and landing phase in each case requires one day, leaving 5 days available for the execution of experiments in earth orbit. In special cases the mission can be extended up to 30 days. The Spacelab crew (male and/or female)will consist of one to four payload specialists who may be principal investigators and may have minimal astronaut-type training. The normal work schedule foreseen is two crew members continuously. Spacelab, however, is designed to allow three crew members to work simultaneously for one shift of 12 hours, followed by one crew member for the second 12 hour shift. Figure 3 shows a double module – two pallet configuration of Spacelab.

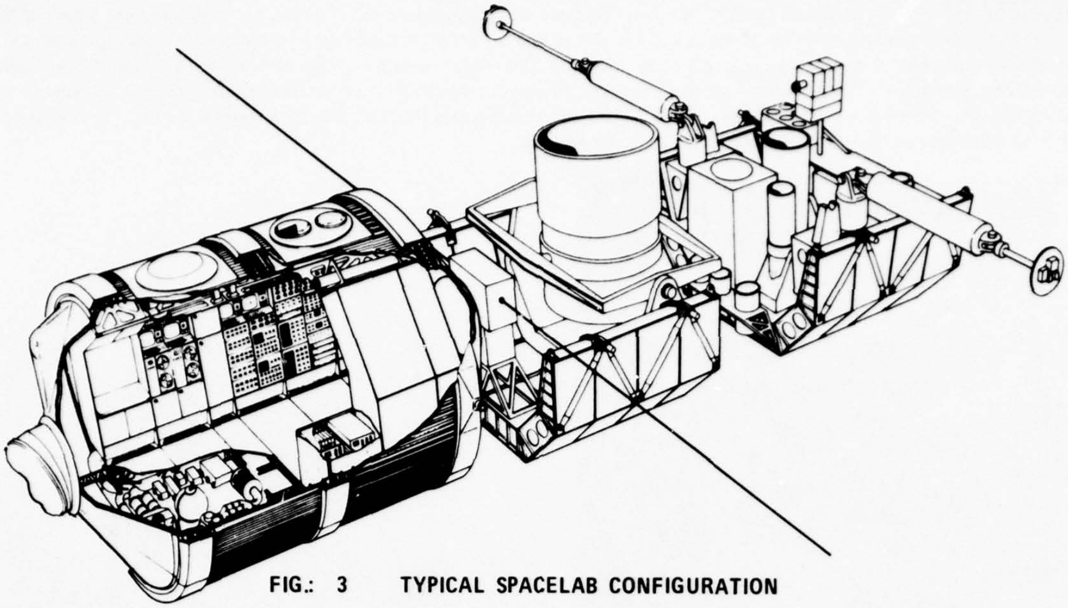


FIG.: 3 TYPICAL SPACELAB CONFIGURATION

SPACELAB INTERNAL ENVIRONMENT

In order to provide the crew earth–like environmental conditions, the atmosphere will be an oxygen/nitrogen mixture at 760 mm mercury $\pm$ 13 mm. The carbon dioxide partial pressure is nominally 5 mm mercury or less than 7.6 mm mercury as the maximum. The air temperature will range between 18^{0} and 27^{0} and a selected value within this range is automatically controlled within a tolerance of $\pm$ 1^{0} C. Humidity is automatically controlled between 7 mm mercury vapour pressure minimum and 70 $^{0}/o$ relative humidity maximum. The minimum value of 7 mm mercury vapour pressure (comparable with 30 $^{0}/o$ to 40 $^{0}/o$ relative air humidity) is an increase compared with Skylab (5.38 mm mercury) in order to avoid the problems experienced there, such as cracked lips, dry mucous membrances of the nose and too dry skin. All places within Spacelab which are accessible to the crew will be within the contact temperature limit of 6^{0} C to 45^{0} C for short–term contact, and for contact of more than 30 seconds, between 13^{0} C to 40^{0} C. All parts which do not fall within this range must be protected. The air velocity within Spacelab will be between 5 and 12 m/minute. General illumination intensity will be 200 to 300 lumen/sqm and at the work bench area, 400 to 600 lumen/sqm. Skylab lighting intensity was judged too low at 50 to 100 lumen/sqm. Maximum noise levels will be less than NC–50 (USA) or ISO NR–50 (Europe) noise limit criteria. This noise level approximately corresponds to that prevailing in a normal office. This comparitively low noise level is made possible by installing most of the subsystem equipment within closed consoles and under the floor.

SPACELAB CONCEPT

Experience gained during the Skylab missions verified that the orientation of the crew is facilitated by a floor/ceiling concept which is similar to the familiar conditions prevailing on earth. This orientation has been used in the Spacelab architecture. As a result of this one – G orientation, other advantages such as ground handling and crew training were also realized. Figure 4 is a view of the Spacelab module showing the floor/ceiling one – G concept.

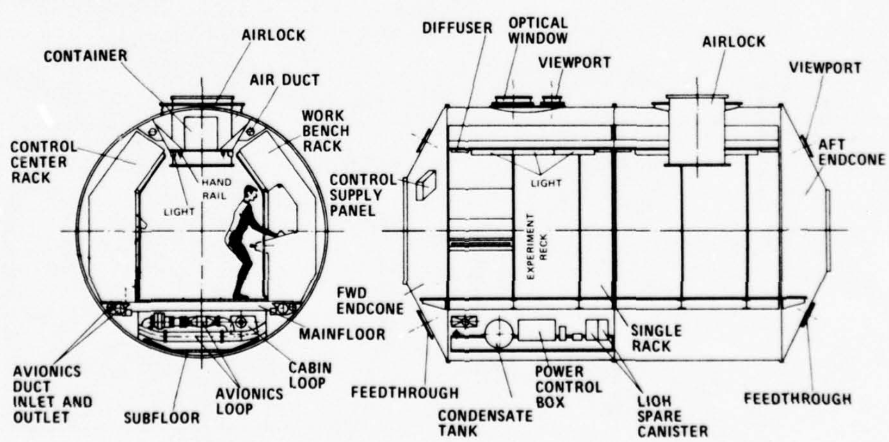


FIG.: 4 SPACELAB ARCHITECTURAL ARRANGEMENT

The above floor area of the first meter of the module is allocated to the operator console on the one side and the workbench on the other side. The remaining space within Spacelab is available for experiment equipment. A comparatively generous free volume of approximately 4 cubic meters per running meter is available as usable volume for the crews' work space, translation, etc.

The equipment and internal layout of Spacelab has been designed to accommodate the extremes of crew dimensions for the 5th and 95th percentile anthropometry/mobility of males and females of the United States and Europe projected to 1980. The practical design impact of this requirement means that Spacelab must allow for the reach capability of the smallest individual and the interference (clearances) for the largest. The influence of this great size differential was most important in the design of the workbench and the operator's console. One point of interest taken from Skylab experience is that the reach envelope is larger in zero – G than in one – G. Figure 5 is a front view of the module as seen in the full scale mockup.

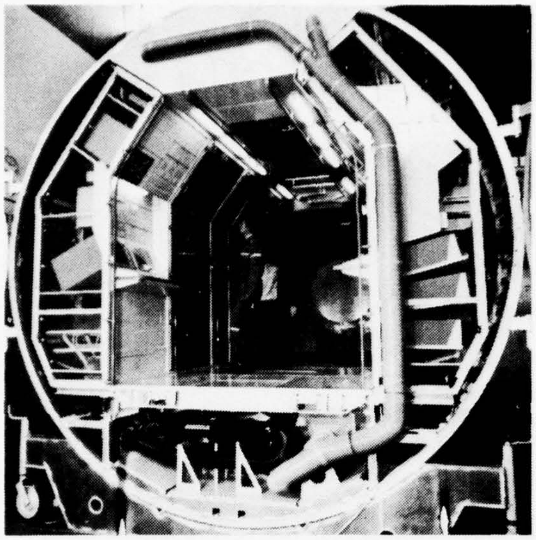


FIG.: 5 SPACELAB MOCKUP

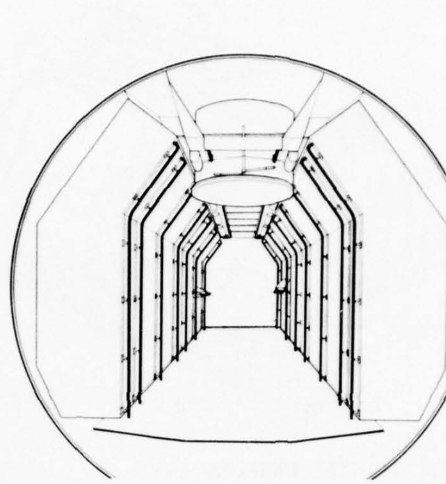


FIG.: 6 HANDRAIL ARRANGEMENT

HAND HOLD / MOBILITY AIDS

Translation in zero gravity is primarily accomplished by pushing off from one surface and grasping a hand hold at the desired stopping position. Recognizing this fact, Spacelab has utilized hand hold/mobility aids generously throughout the module. The handrails which are mounted in the consoles and on the ceiling are expected to be used as mobility aids while the handrails provided at the viewports, optical windows and experiment airlocks also serve the purpose of short-term positioning of the body. The mounting of handrails requires an extensive study of the system involved and the functions to be performed. If during the course of this investigation, the result is that the function to be performed requires a dwelling time of several minutes, foot restraints must be supplied. Figure 6 shows the arrangement of the handrails within the module.

FOOT RESTRAINTS

Each console in Spacelab provides for a foot restraint which is vertically adjustable in any position and pivotable in 15 degree increments. In Figure 7 the system of the foot restraints is shown with its possible positioning. Also shown in diagram form are the many possible positions available using the foot restraint.

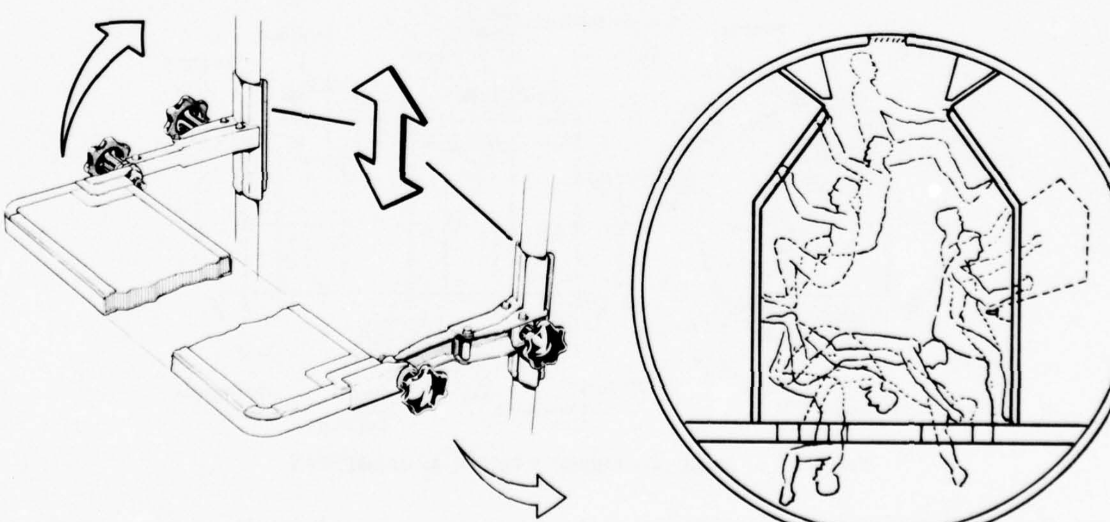


FIG.: 7 FOOT RESTRAINT SYSTEM

The *triangle shoe* which was used in Skylab (Figure 8a) functioned well during the missions but was heavy and did not wear well. It also required a special attachment floor. NASA has developed an improvement which works well in a sea level equivalent atmosphere and overcomes the traingle shoes deficiencies. It is a suction cup shoe (Figure 8b), however, the basic concept of restraining the feet will be the same.

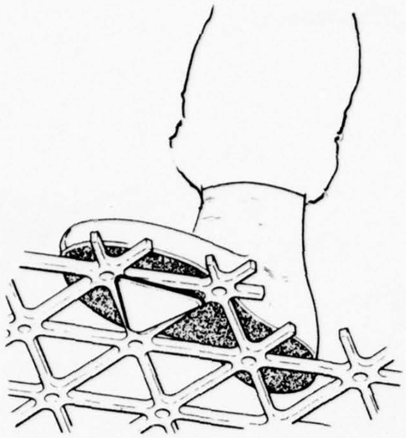


FIG. 8a TRIANGULAR SHOE

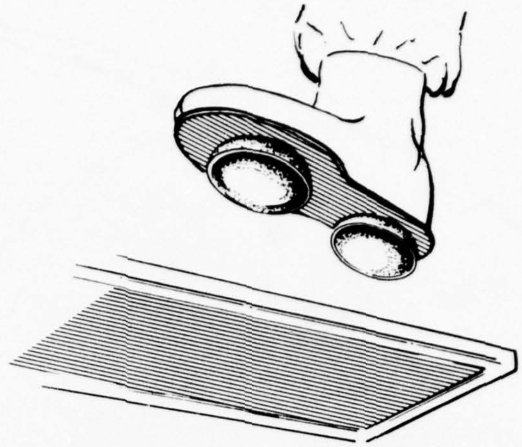


FIG. 8b SUCTION CUP SHOE

For optimization of the foot restraint locations and in particular for the determination of the distance between the feet and the console front surface, full scale models were built. Definite values for the positioning of the foot restraints were determined in the water tank of the Marshall Space Flight Center, Huntsville, Alabama. The results of these tests are reflected in Spacelab design. Figure 9 shows a sketch of the foot restraint forward, backward and side functional reach envelope. Figures 10, 11, and 12 are photos taken in the water tank while determining the optimum position of a person in front of a work bench.

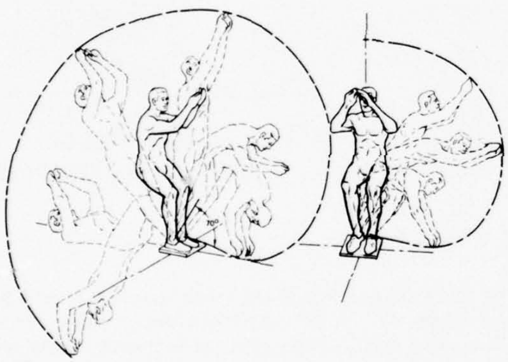


FIG.: 9

FOOT RESTRAINT FUNCTIONAL REACH

FIG.: 10

FOOT RESTRAINT – SIDE REACH

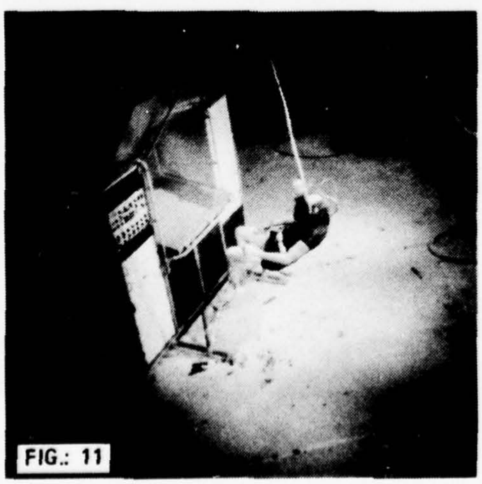


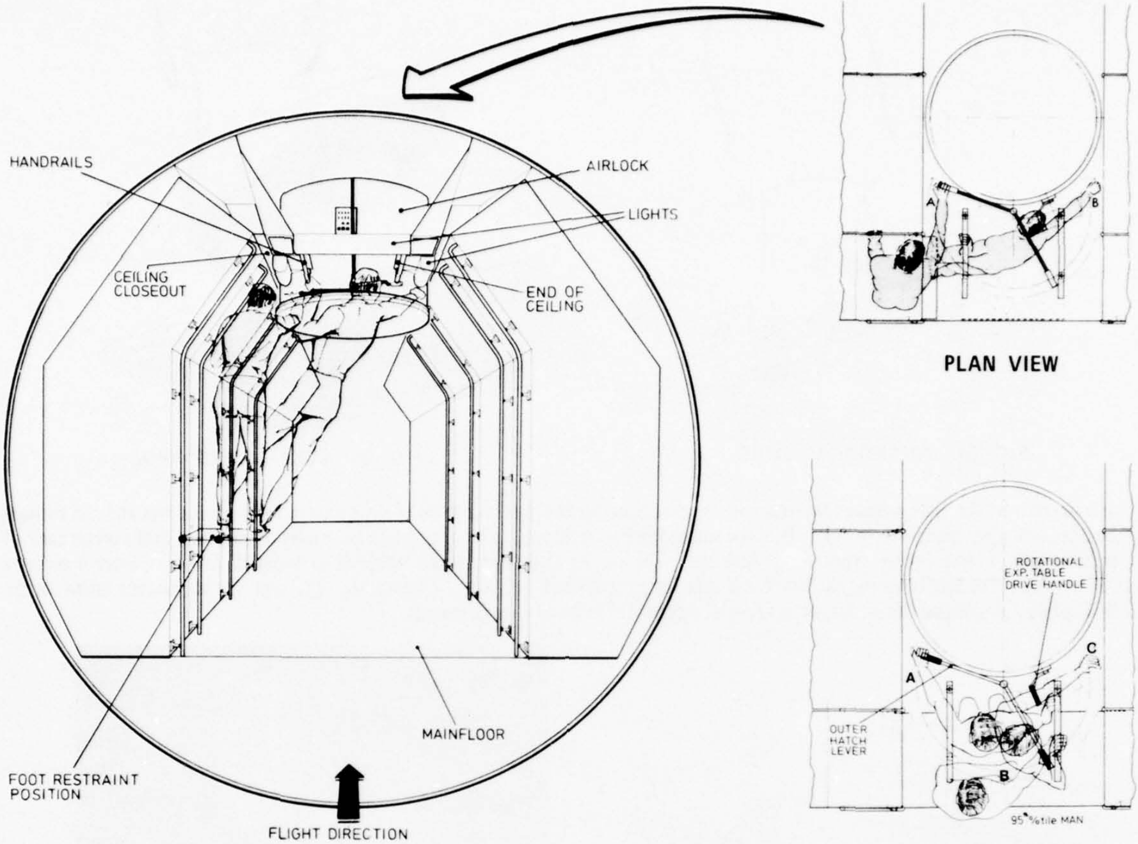
FIG.: 11

FOOT RESTRAINT – BACKWARD REACH

FIG.: 12

FOOT RESTRAINT – WORKBENCH ACTIVITIES

A typical example of utilization of the hand rails in conjunction with the foot restraints is in the accessibility and utilization of the air-lock. Perspective drawings were prepared showing the various potential positions the crewman might assume in working with the air-lock controls and displays, handles, cover, etc., and an evaluation of the available foot restraint and hand hold provisions was made. (See Figure 13).



PLAN VIEW OF ALTERNATE PROCEDURE

FIG.: 13 AIRLOCK OPERATION

To further evaluate the usefullness of the provided restraint systems a full scale mockup was built and a crew systems engineer utilized a simulated time line analysis to verify accessibility, clearances, view considerations, etc. If future questions arise concerning the human engineering aspects of the airlock or any other man/machine design problems, more sophisticated studies can be persued through utilization of neutral bouyancy (under water) tests. Figure 14 shows a full scale mockup of the Spacelab airlock arrangement being evaluated.

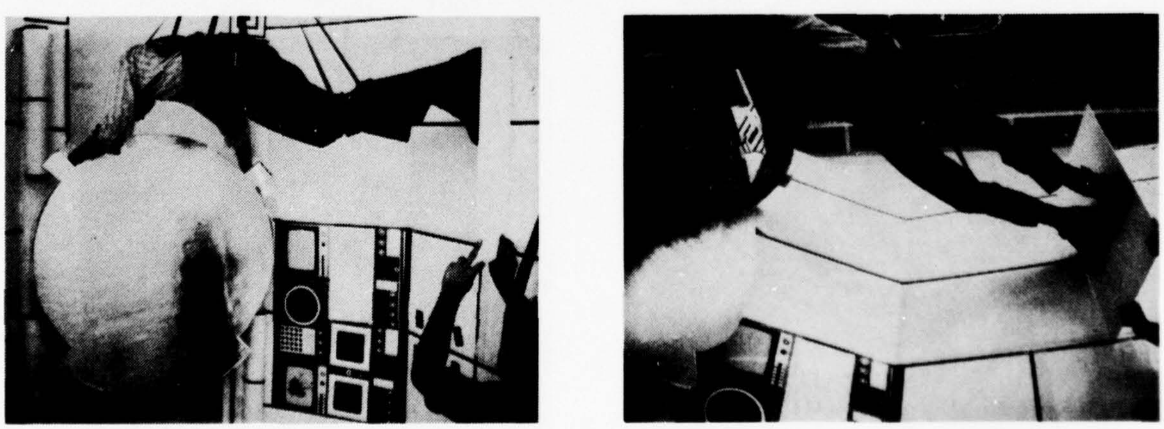


FIG.: 14 EVALUATION OF AIRLOCK TASKS AT A FULL SCALE MOCKUP

Another example of restraint utilization is in accessing the overhead stowage containers. (See Figure 15).

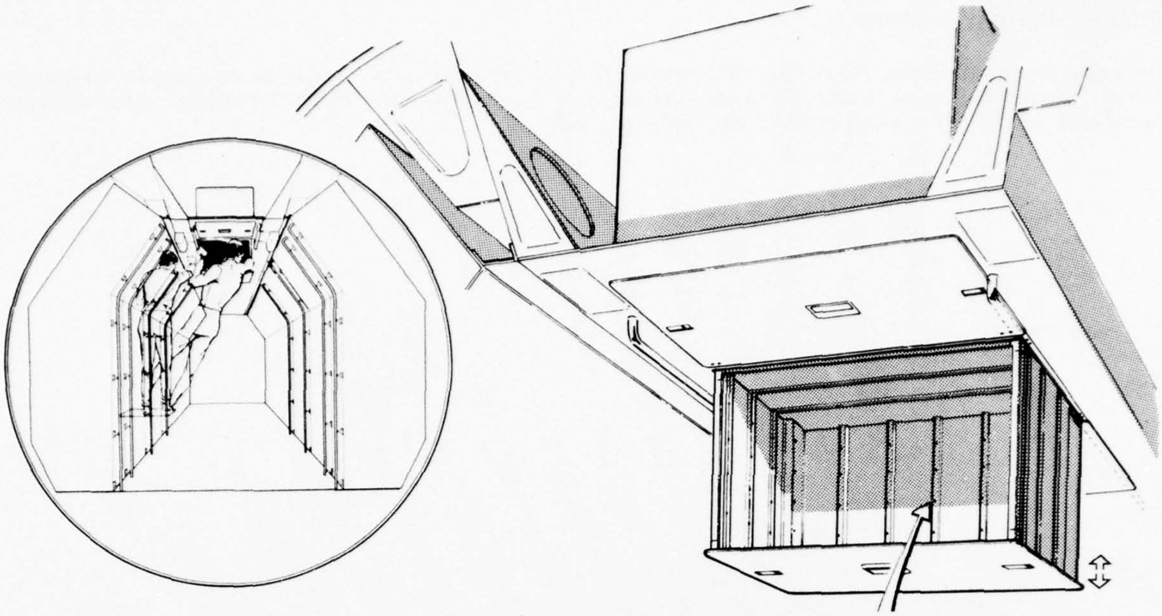


FIG.: 15 ACCESS OF OVERHEAD STOWAGE CONTAINER

WORK BENCH

Skylab experience revealed that a general workbench area should be provided in the module, having the following features:

- o Allow restrained crewman to address it in a conventional manner.
- o Slant the prime surface to maximize access.
- o Utilize surrounding surfaces to complement prime surface.
- o Provide capability to contain and/or restrain small articles.
- o Accommodate equipment restraints to secure equipment and documents for operation, analysis and maintenance.
- o Provide convenient storage of tools and supplies within reach of the crewman addressing the workbench.
- o Provide power outlets for operation of power tools and instruments.
- o Provide lighting free of shadows.

The Spacelab workbench meets these requirements. The design of the workbench was carried out with the expectation that lengthy dwelling times would be required at this bench. Because of this it was decided to design the workbench for the zero – G neutral position of man. Figure 16 shows a sketch of the workbench arrangement along with a full scale mockup.

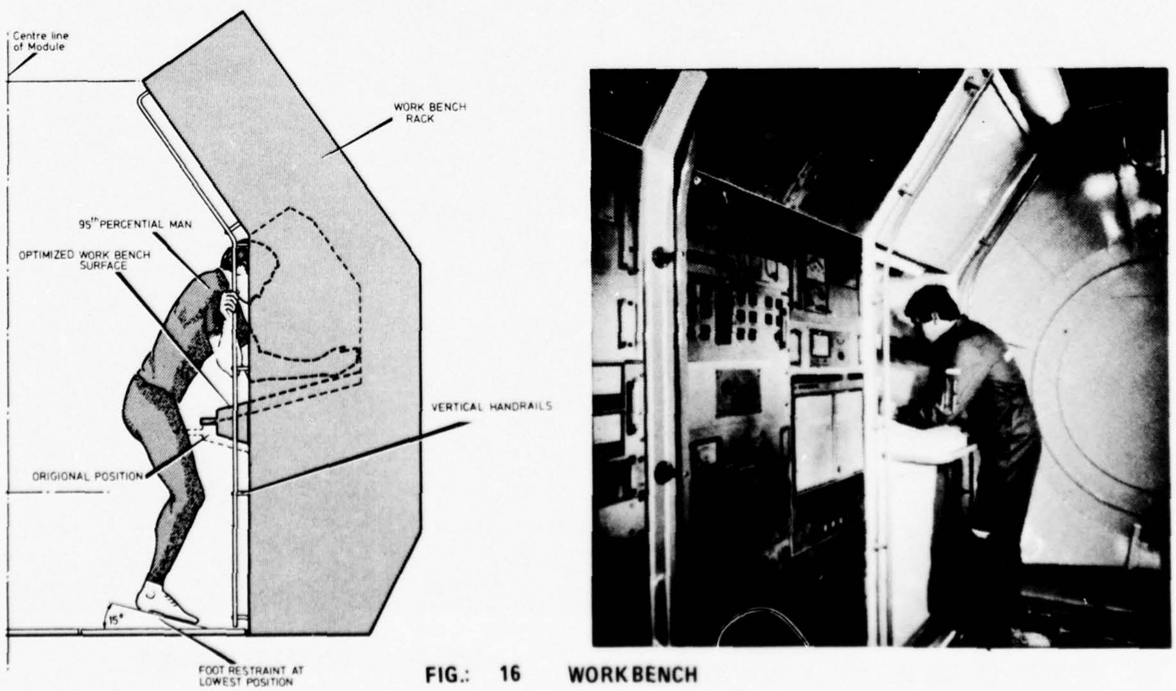


FIG.: 16 WORKBENCH

ZERO – G NEUTRAL POSITION

The neutral position which man automatically assumes under zero – G conditions was evaluated in the water tank for the design of Skylab. Pictures were also taken during the Skylab missions to verify this neutral position. Figure 17 shows the results of the Skylab photographs, and Figure 18, the values obtained earlier in the water tank.

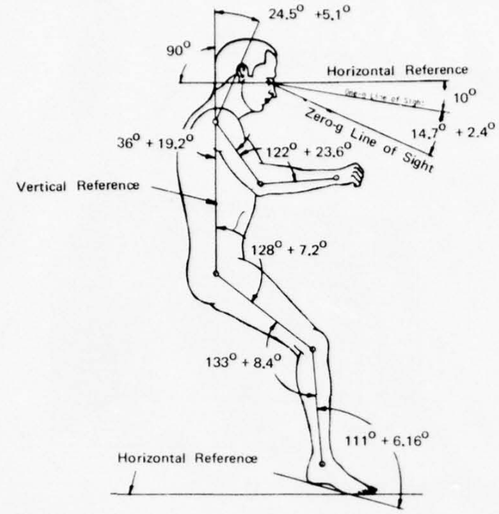


FIG.: 17 ZERO–G POSITION
DERIVED FROM SKYLAB FLIGHTS

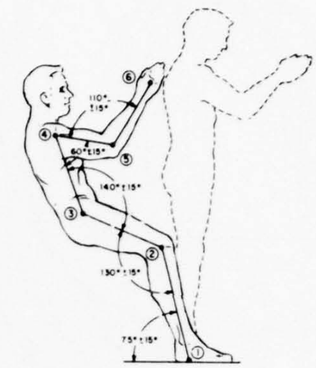


FIG.: 18 ZERO–G POSITION
DERIVED FROM WATER TANK TEST

Due to the fact that both results differ only slightly, the Spacelab design of the workbench which was designed to the Figure 18 position also conforms to Figure 17. The new data had no influence on the reach nor on the capability of reading identification markings. Figure 19 is a picture taken of astronaut Dr. Ed. Gibson in the relaxed neutral position while on his Skylab III mission. Confirmation of the agreement of theory and practice was of equal importance for the design of the operator console. This unit of Spacelab supports the control of subsystems and experiments. The design of this console and, in particular, the optimum arrangement of the control and indicating instruments is at present still under preparation. Figure 20 shows two concepts of an operator console and a crewman in zero – G position in front of it.

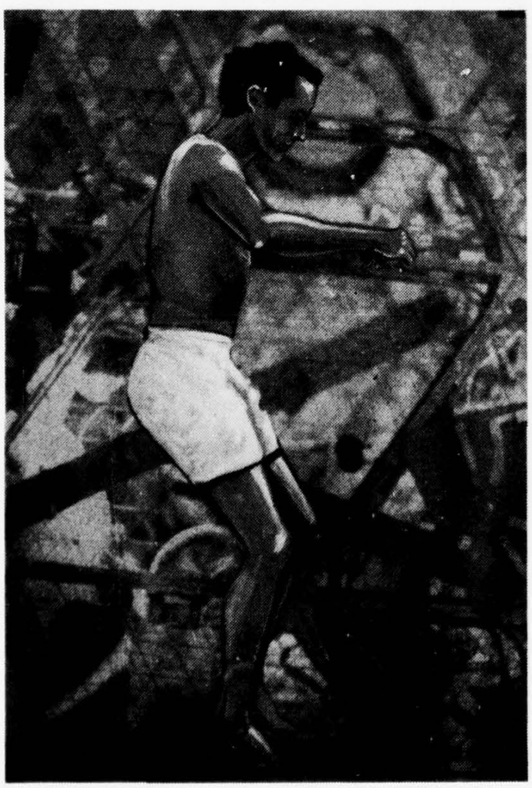


FIG.: 19 SKYLAB III ASTRONAUT
DR. ED GIBSON IN ZERO–G POSITION

FIG.: 20 OPERATOR CONSOLE

CONCLUSIONS

The evolution of Spacelab interior design has recognized and met the need to provide accommodations for man in the unusual zero – G environment. Human engineering, both classic one – G and the relatively new zero – G data from Skylab and other neutral bouyancy tests, has been utilized to develop what hopefully will prove to be a well integrated man-machine system. Skylab carry-over design has been very influential in the design of Spacelab and Spacelab in turn will surely provide additional information to be used for "Human Engineering" of future manned space programmes. It will be enlightening to see how well we have provided for the non-astronaut type crew members of the future Spacelab missions.

BIBLIOGRAPHY

1. Spacelab Systems Requirements, ESTEC SLP/2100, Issue No. 5, ESRO/ESTEC Spacelab Project, 11 Nov. 1974.

2. Lessons learned on the Skylab Program, NASA–MSFC Skylab Program Office, Huntsville, Alabama, 22 Feb. 1974.

3. Lessons learned on the Skylab Program, NASA–JSC, Houston, Texas, 6 March 1974.

4. Havens, D. E. – Johnson, G. A. – Jencks, H. S.
Null Gravity Restraint Characteristics – Paper Presented at the Aerospace Medical Association 41st Annual Scientific Meetings, St. Louis, Missouri, 27–30 April 1970.

5. Johnson, C. C. – Habitability / Crew Quarters, Paper Presented to the American Astronautical Society Twentieth Annual Meeting, Los Angeles, Calif., 20–22 August 1974.

ACKNOWLEDGEMENT

The authors wish to acknowledge the assistance of Mr. A. Ward, LSIA who prepared all of the line drawings for this paper.

DISCUSSION

M.W.Whittle: As far as suction cup foot restraints are concerned:

(1) how do you fix on?
(2) how do you release?
(3) do you stick on accidentally when trying to use the feet to "push off" across the spacecraft?

V.G.Munkelt: The answers are:

(1) Attach to plane.
(2) Released by tether mounted between shoe and cup actuated by an unusual movement of the foot.
(3) No accurate answer, one doesn't expect it in most of the cases, but it may happen.

K.Kraiss: During your presentation you were talking mainly of workspace layout. This of course is only one aspect of human engineering. Were you also concerned with:

(1) Task design,
(2) Crew integration,
(3) Function allocation and related points.

W.G.Munkelt: (1) Yes, we were concerned by task analysis (only on subsystems level).

(2) Crew integration to the level in which Spacelab is involved, not within shuttle/orbiter.

(3) Yes, for the third point, but only on subsystem level.

THE EFFECTS OF PROLONGED SPACEFLIGHT ON THE REGIONAL DISTRIBUTION OF FLUID, MUSCLE AND FAT: BIOSTEREOMETRIC RESULTS FROM SKYLAB

by

Squadron Leader M W Whittle, MSc, MB, BS, RAF
RAF Institute of Aviation Medicine
Farnborough, Hampshire GU14 6BD, England.

R E Herron, PhD and J R Cuzzi, BSc
Texas Institute for Rehabilitation and Research
Houston, Texas 77025, USA.

C W Keys, BSc
Technology Incorporated
Houston, Texas 77058, USA.

SUMMARY

Biostereometric analysis of body form was performed several times preflight and postflight on the astronauts of all three Skylab flights. The analysis was made by deriving the three-dimensional coordinates of numerous points on the body surface from stereoscopic pairs of photographs of the subject, using a stereoplotter. The volume of segments of the body, and of the body as a whole, was calculated by integration of cross sectional areas derived from the coordinate data. All nine astronauts demonstrated regional changes in volume distribution which could be related to changes in total body water, muscle mass, and fat deposits. The change in water resulted from a redistribution of fluid in response to zero gravity. Changes in muscle mass resulted from an alteration in patterns of muscular activity in the absence of gravity, and changes in fat resulted from discrepancies between the individual's caloric needs and his food consumption.

INTRODUCTION

The weightlessness experienced during spaceflight has two main effects on the body: it abolishes the normal hydrostatic pressure gradient from head to feet, and it permits posture control and locomotion to be accomplished by very much less muscular activity than would be required in a gravitational field.

Figure 1(A) shows the normal pooling of blood in the lower limbs due to gravity. On acute exposure to zero gravity the venous tone in the lower limbs displaces blood into the upper part of the body, and causes an increase in the volume of the central venous pool, shown in Figure 1(B). A negative fluid balance exists for 2-3 days, probably mediated by the Gauer-Henry reflex, and the central venous pool returns to its previous volume, in the presence of a diminished intravascular and extracellular fluid volume, Figure 1(C). Upon return to a gravitational field, as in Figure 1(D), pooling of blood in the lower limbs again occurs, with a reduced central venous pool and a marked tendency to orthostatic hypotension. Retension of fluid occurs, and the pattern of Figure 1(A) is restored in 3-4 days. The fluid changes resulting from spaceflight are thus a 'stepwise' loss of fluid in the 2-3 days immediately following orbital insertion, and a stepwise replacement of that fluid in the 3-4 days following return.

In zero gravity muscular activity is not required to maintain the posture of the body, as it is on earth, except when the crewman is attempting to perform a task requiring his position to be stable. Movement about the spacecraft requires very little muscular activity, normally being accomplished by pushing off in the required direction with the hands, and catching hold once the destination is reached. The total amount of muscular activity would thus be expected to be decreased, with a change in emphasis taking place, the arms being used more than the legs. The reduction in total energy expenditure should result in a diminished caloric requirement, and unless food intake were similarly reduced, an increase in body fat would be expected.

The Skylab programme consisted of three space flights, with three astronauts on each occasion occupying the space station for periods of 28, 59 and 84 days, giving a total of 513 man-days exposure to weightlessness.

It was proposed to study the changes in body composition on the Skylab flights, but due to the many demands on the astronauts' time around launch and recovery, and to the fact that the first two days postflight were spent on board ship, some of the more conventional techniques, such as underwater weighing, could not be attempted. Gross body composition was determined by isotope dilution (tritium for body water, and potassium 42 or 43 for exchangeable potassium), and by the relatively new technique of biostereometrics.

Biostereometrics is the science of measuring, and describing in mathematical terms, the three-dimensional form of biological objects. Changes in the quantity and distribution of fluid, muscle and fat may be inferred from changes in the volume of selected parts of the body. An extensive background to the science has been given by Herron (1972).

METHOD

The biostereometric measurements of the Skylab crewmen were made by four-camera stereophotogrammetry, during the immediate preflight and postflight periods. Photographs were taken of each astronaut three times before flight, to establish a baseline, and postflight during the 24 hours following splashdown. On the first two Skylab missions, a further set of photographs was taken one month later. On the final flight,

photographs were obtained on recovery day, on recovery plus one and recovery plus four days, and again after two months. The subjects were weighed within a few minutes of taking the photographs.

The layout of the apparatus is shown in Figure 2. The subject stood between two control stands, which provided dimensional information in the three orthogonal axes. He was photographed simultaneously by two cameras in front, and two cameras behind. The subject was nude except for an athletic supporter, and a skullcap to press his hair down. To minimize variations in chest volume, photographs were taken in maximal forced exhalation. Between each pair of cameras was a strobe projector, which through a focusing lens projected a pattern of lines onto the subject's skin, making it easier to visualize during the subsequent plotting process. After development the plates were analyzed on a stereoplotter, which derived the three-dimensional coordinates of between 3000 and 5000 points on the body surface, punching them on IBM cards for subsequent computer analysis.

Body landmarks were located on frontal and lateral views of the subject, which were generated by computer from the coordinate data. These landmarks were used to define particular body segments, such as the chest, buttocks, and arms. A computer program then derived the area, shape and perimeter of between 80 and 100 sections of different parts of the body, and the volume and surface area of the body as a whole, and of the body segments

RESULTS

Preliminary results from the second Skylab flight have been previously reported (Whittle et al, 1976).

Table 1 gives the preflight mean volume of the body and its segments for the nine Skylab astronauts, and the change observed at the first postflight measurement. Body weight is also given. Although all the body segments examined showed a postflight reduction in volume, the changes observed in the chest and arms were small, and not statistically significant. The greatest absolute losses of volume were seen in the abdomen and thigh, although the calves showed a greater proportional loss. The loss in total body volume (2.34 L) appears to be too low for the loss in body weight (3.03 kg), but this difference is not statistically significant, and probably results from the accumulation of inaccuracies when the volume of the whole body is calculated. The Skylab data are currently being reanalysed by new techniques, and it is hoped that more accurate results will be available in the future.

The rate of recovery of body volume was followed only on the final Skylab flight, in which three sets of photographs were obtained in the first five days postflight. Table 2 gives the difference, for various body segments, between their mean preflight volume and the three postflight measurements. The abdominal volume varied a great deal, as it is sensitive to food and drink intake - the recovery plus one day measurements were made in the middle of the day, whereas the recovery plus four days measurement was made before breakfast. Nonetheless, a marked increase in volume was seen between recovery day and the other 2 measurements. Buttock volume increased by 0.20 l during the postflight period. Both the thighs and the calves showed a rapid increase in volume, the rate of increase being initially greater in the calves, although by recovery plus four days the thighs had reached their preflight volume, whereas the calves were still 0.12 l deficient.

DISCUSSION

It is unfortunate that the pressures on the time of the astronauts prevented more photographic sessions being scheduled, particularly during the first few days following splashdown. However, the data collected do provide some interesting pointers to the changes in body composition resulting from space flight. The rapid increase in volume in the first five days postflight clearly resulted principally from the 'stepwise' increase in fluid volume occurring on re-exposure to gravity. The recovery of volume proceeded faster in the calves than in the thighs, due to their more dependent position.

All the astronauts showed a rapid increase in weight in the first few days postflight, but the weight had generally levelled out by recovery plus four days, suggesting that rehydration was complete. The volume changes observed in the final crew at that time may be taken to represent the sum of the inflight changes in fat and muscle, modified by whatever changes in these components had occurred in the first four days postflight.

The postflight change in volume of the buttocks for the nine Skylab astronauts correlated well with the postflight change in weight (correlation coefficient 0.92) suggesting, as might be expected, that the buttocks are a sensitive indicator of body fat. Using the regression equations from this correlation, and correcting for the effects of dehydration on the volume of the buttocks, it has been calculated that around 2.2 kg of the postflight weight loss resulted from the combined loss of fluid and muscle, the remainder being due to changes in body fat.

The final Skylab crew relaxed their dietary and exercise regimes following the flight, and put on weight. The resulting change in volume of different body parts enabled a correction to be made for subcutaneous fat in the postflight volume changes. If the changes in volume due to both fluid and fat are known, the change in muscle bulk may be calculated. With the small number of data points, such calculations must be taken as very approximate, but there appears to have been a mean loss for the final Skylab crew of about 90 g of muscle from each calf, and about 70 g from each thigh. Such losses are very modest, and are a tribute to the inflight exercise program. With even fewer postflight data points, it is possible only to make very rough estimates for the first and second Skylab crews. The loss of muscle from the calf appears to be similar from one mission to another, whereas the loss of thigh muscle apparently decreased with succeeding missions. This observation fits in well with the use of the bicycle ergometer, which was increased on successive missions, but which provides better exercise for the thigh muscles than for the calf.

A correlation coefficient of 0.92 has been established between the change in buttock volume over the course of the flight and the inflight caloric intake, expressed per kilogram of lean body mass (LBM). LBM was derived from total body water and exchangeable potassium, measured by isotope dilution. A caloric

intake of 49 kcal/day/kg LBM appears optimal to preserve the body fat at its preflight level. Only one Skylab crewman exceeded this intake, and he increased his body fat. The two crewmen losing the most fat in the course of their flight had intakes of 37 and 41 kcal/day/kg LBM. The remaining crewmen had intakes in the range 45-48 kcal/day/kg LBM, and all but one lost a little fat.

CONCLUSIONS

The nine Skylab astronauts returned from their space flights with changes in the quantities of fluid, muscle and fat in their bodies. The change in fluid resulted from the adaptation of the cardiovascular system to the zero-g environment, and amounted to a deficit of 1.5-2.0 l. It was replaced in the first four days postflight. The losses of muscle were fairly modest, amounting to about 160 g in each leg on the final mission. Losses were a little greater, particularly in the thigh, on the first two flights, and reflected the level of exercise undertaken. Techniques have not yet been devised to measure changes in muscle bulk in the upper part of the body, but no statistically significant changes in the volume of the arms or chest were observed. Changes in body fat were related to caloric intake, an inflight intake of 49 kcal/day/kg lean body mass appearing to be necessary to preserve the body fat at its preflight level, a value which was exceeded in practice by only one crewman.

Biostereometrics is a relatively new science, but it is emerging as a powerful tool in the medical and biological sciences. The stereoscopic photographs of the Skylab astronauts took no more than five minutes of the subjects' time for each measurement, but provide a permanent and detailed record of body form, which may be re-examined at any future date, either to answer new questions, or to take advantage of the increased accuracy resulting from improvements in the analytical technique.

REFERENCES

1. HERRON,R.E. Biostereometric Measurement of Body Form. Yearbook of Physical Anthropometry 16, 1972, 80-121.

2. WHITTLE,M.W., HERRON,R.E. and CUZZI,J.R. Biostereometric Analysis of Body Form: The Second Manned Skylab Mission. Aviat. Space Environ. Med. 47, 1976, 410-412.

ACKNOWLEDGEMENT

The photography and stereoplotting were performed by the Biostereometric Laboratory, Texas Institute for Rehabilitation and Research, under NASA Contract NAS9-11604.

Figure 1: Response of the Circulating Blood Volume to Zero Gravity.

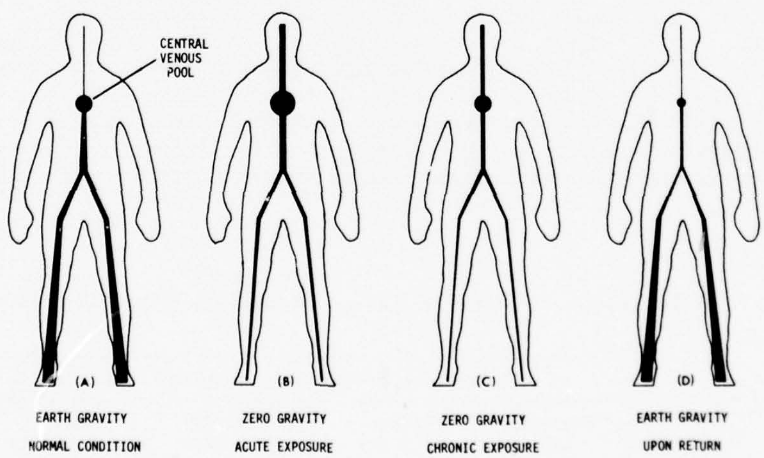


Figure 2: Diagram of Stereometric Apparatus.

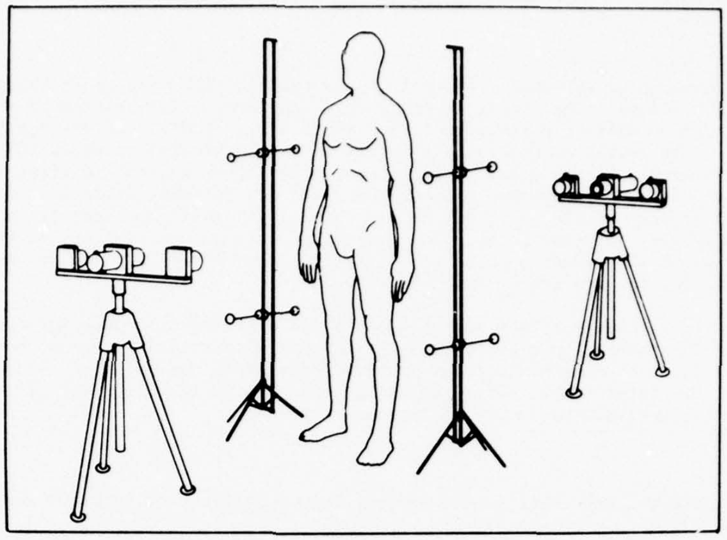


Table 1: Difference between mean preflight and first postflight measurements of regional and total body volume and body weight; all Skylab crewmen (9 subjects).

	Preflight Mean Volume	Postflight Volume Change	Proportional Volume Change	Significance
	litres	litres	percent	(paired t-test)
Arms (both)	6.93	-0.07	-1.0	N.S.
Chest	13.51	-0.15	-1.1	N.S.
Abdomen	11.31	-0.54	-4.8	$p < 0.001$
Buttocks	13.58	-0.39	-2.9	$p < 0.005$
Thighs (both)	9.41	-0.56	-5.9	$p < 0.001$
Calves (both)	6.35	-0.47	-7.4	$p < 0.001$
Total Body Volume	71.27	-2.34	-3.3	$p < 0.001$
Body Weight (kg)	71.99	-3.03	-4.2	$p < 0.001$

Table 2: Postflight change in volume of body segments; final Skylab crew (3 subjects).

	Change from Preflight Mean Volume (litres)			
	Recovery Day	Recovery + 1 Day	Recovery + 4 Days	Recovery + 68 Days
Abdomen	-0.57	+0.19	-0.12	+0.41
Buttocks	-0.04	+0.03	+0.16	+0.85
Thighs (both)	-0.43	-0.32	+0.01	+0.78
Calves (both)	-0.45	-0.27	-0.12	+0.31

DISCUSSION

C.E.Giannopoulos: In the eventuality of a changing amount of gas in the gastro-intestinal tract and in the respiratory system, with definite effect on the abdominal and thoracic volumes, how do you eliminate this artifact, which might falsify your biostereometric measurements?

M.W.Whittle: There was no control over gastro-intestinal gas. Whenever possible, the photographs where taken before breakfast, and it was hoped that the volume of gas would be reasonably reproducible from one photographic session to another.

OPHTHALMOLOGICAL REQUIREMENTS FOR SPACELAB ASTRONAUT-SCIENTISTS

by

F.-J. DAUMANN, LtCol., GAF, MC
German Air Force Institute of Aviation Medicine
Fürstenfeldbruck

SUMMARY

Ophthalmological requirements for visual acuity, field of vision, binocular vision, accomodation, color vision, and equilibrium of eye muscles are presented from an occupational medical point of view. Assessment of visual acuity, for example, is based on the proven principle of ergophthalmology, that maximum visual acuity in relation to optimal performance should be at least twice as high as the visual acuity necessary for the efficient performance of routine tasks.

Correction of visual deficiencies by means of glasses and contact lenses is discussed. The necessity of full visual field, binocular vision, dark adaptation and color vision is stressed next anomalies and deseases compatible with the stresses of a payload-specialist and those causing rejection are covered. Of course the criteria must be that necessary tasks have to be performed without impairment of efficiency in spite of the anomalies, and that the astronaut-scientist is not required to play an active role in the flight safety of the SPACELAB.

Studies by SCHMIDTKE and SCHOBER (1) show close correlation of optimal work performance with visual performance. Therefore requirements for the visual organ - by far our most important sensory organ - have been set down for most occupations in our industrial society, SCHOBER (2). As most recent occupational branch that of the payload-specialist has been added through the SPACELAB Shuttle Project. The following is an attempt to present the performances required of the visual organ of the astronaut-scientist in order to be able to meet the requirements of a mission under SPACELAB working conditions.

The following prerequisites (3, 4) and tasks must be met by payload-specialists, of whom up to four fly along in a single mission:

1. Experience in experimental operations,

2. Responsibility for the determination of experimental objectives,

3. Responsibility for the planning of the experimental sequence,

4. Knowledge of the heating- and control systems,locks, tunnel and rescue systems,

5. Experience in the maintenance and repair of defective experimental installations.

Aboard the SPACELAB the activities of the payload-specialist have no immediately operational effect on flying safety, however, errors on his part may have an indirect bearing on flying safety keeping in mind that it is he who controls the SPACELAB atmosphere (composition of gases, humidity, pressure and temperature), that he must supervise cooling systems throughout the experiments, thermal-load of the apparatus on the pallets and perform repairs on electronical and electrical systems. Be it for the biologico-medical experiments (5), for the speciality of material research and industrial processing engineering, for the physico-chemical experiments, stellar astronomy or solar physics, the visual organ is always of decisive importance in the performance and control of these activities. In all experiments, observation, assessment and qualitative description of tests and test objects is the foremost task of the payload-specialist. It must be added that in all space flights the visual sense is of particular importance in the state of weightlessness since it must compensate for the missing input on part of the vestibular organ. Orientation in space during weightlessness and in deep darkness has always been a fiasco for the astronauts in earlier missions.

In clarifying, which visual performance is sufficient for the job as payload-specialist, it must be considered that a number of visual functions combined make up visual performance. This includes:

- differential capability, i.e. contrast vision,
- shape perception, that means the faculty of the eye to discriminate certain outlines from others,
- visual acuity, i.e. the ability to separately perceive adjacent objects,
- the field of vision, accommodation and color vision,
- binocular vision,
- equilibrium of eye muscles.

There is a direct dependency between the luminance of the visual field and visual performance HARTMANN (6), SCHOBER (7). For a difficult visual task a high amount of contrast is required, for a simple visual task only little contrast. Visual performance will at first increase with increasing luminance of a visual field, will then reach a maximum value and will again decrease during very high luminances due to blinding.

In the SPACELAB a compromise must be achieved concerning illumination between physiologico-optical requirements on one hand and the technical possibilities on the other. The requirements pertaining to illumination and design of a manned SPACECRAFT have been compiled by the National Aeronautics and Space Administration in the "General Specification" SC-L-0002 (8) and also apply to SPACELAB.

The lighting subsystem shall provide interior and exterior lighting during the mission to allow the crew members to locate, operate and read all displays, controls and nomenclatures. The main lighting is provided by broad beams of flood lights of 6 lamps for each module of the fluorescent type made by Philipps. The general illumination will amount to 200 lux = 18 fdcd measured 1 m above the ground. Special work consoles are illuminated with 400 lux = 36 fdcd. 20 lux = 1,8 fdcd have been provided as emergency lighting. The brightness of all illuminated instruments and indicators will range between 3,4 fd-la = 11,58 cd/m^2 and not less than 1,80 fd-la = 6,17 cd/m^2.

The contrast of finishes depends upon the color of the display of panel nomenclatures and markings and will be sufficient for the recognition of labeling. Details may be obtained from above mentioned requirements (8).

The luminance provided is fully adequate for subjects having 20/20 vision, even more so since with 1 cd/m^2 and a contrast of 50%, an acuity of 1,0 = 20/20 can be reached HARTMANN (6), SCHOBER (7). A contrast level of 50% implies that a recognizable detail has aquired half the luminance of its immediate environment. Provided there is normal dark adaptation the occurence of night-myopia for far-respectively night-presbyopia for near-vision, i.e. a restriction of accommodation ranges, is not to be expected under the given luminance and brightness and can be neglected.

The information is supplied via digital indicators or in the form of alpha-numeric codes. A data-display-unit with 22 lines of 47 characters with a maximum height of 4,8 mm and a width of 3,2 mm is used. At this size the characteristics from a distance of 33 cm appear under an angle of view of 50 minutes (1 minute of angle = 0,1 mm lateral displacement at 33 cm distance), from a distance of 1 m under an angle of view of 16 minutes.

To recognize these characteristics, a corrected vision of less than 0,5 = 20/40 would be fully adequate for near vision, considering that maximum acuity with a view towards optimal performance should at least be twice as high as the acuity necessary for the efficient performance of tasks HARTMANN (6). For certain experiments a higher visual acuity will be required, for instance when working with microscopes, with electrophoretic techniques, when doing precision repair work on circuit systems etc. In such cases near vision of 20/20 is called for.

The dimensions of the SPACELAB (length 2694 mm, width 2134 mm, height 2142 mm) will at first suggest that good near-vision and vision up to 2,5 m is more called for than good far-vision. But the tasks of the payload-specialists also include the external observation of the payload-bay during operations of the OMS (3) (orbital maneuvering subsystem) and the observation of outer space and its objects. During extravehicular activities in the pressure suit sufficient visual acuity without glasses is mandatory. Wearing glasses in a pressure suit may lead to considerable impediments (fogging caused by perspiration, dislocation), since there is no possibility to correct these deficiencies. Thus, visual acuity without glasses should not be below 50% = 20/40 for payload-specialists required to do these tasks.

Work performance may be impaired considerably by asthenopias. These may be caused by:

1. Refractive anomalies
2. Lacking visual acuity
3. Constant antagonism between accommodation and the impulse of convergence induced by fusion, as in the case of hyperopia
4. Heterophorias or latent strabisms
   (to avoid double vision, a considerable fusion impulse is effective)
5. Presbyopia
6. Environmental factors
   a) Insufficient illumination at place of work
   b) Too much precision work
   c) Luminance too low in relation to work required
   d) Illumination not steady enough
   e) Diffuse illumination
   f) Direct and indirect blinding
   g) Gloss of reflecting surfaces
   h) Luminance differences within field of vision too great
   i) Flickering of light sources
   j) Twilight effects.

For this purpose refractive anomalies, also latent ones, must be corrected to avoid asthenopia. This comprises correction of myopia as well as hyperopia, astigmatism and presbyopia. At first correction will have to be achieved with glasses provided with special holding arrangements. One astronaut of a SKYLAB-mission has already gained experiences with glasses. Since no studies have been made on wearing of contact lenses in a state of weightlessness, these should not be tolerated for the time being. Surely the "headfullness" described by SKYLAB-pilots as occurring after the

first day of weightlessness and lasting until the fourteenth day explained with fluid shift will influence compatibility GIBSON (9). Soft lenses, in my opinion, stand the best chance, but here again we have the problem of hygiene. This problem should be investigated during the first SPACELAB-missions.

Important for the successful (e.g. binocular microscopes, binocular telescopes) and safe work aboard the lab as well as for handling of the OMS and during extravehicular activities is binocular vision. Six handgrips in the double module on each side, 573 mm up to 1062 mm apart, extend from the ceiling vertically along the wall down to the floor. Safe locomotion along the grips requires stereoscopic vision. This means exclusion of diplopia and of paralysis of any muscle function in any direction.

Because of their classification as pathological processes peripheral or central scotomas should be cause for rejection.

Color vision must not be underestimated since the payload-specialist must differentiate between a variety of signal lamps and is further required to discriminate during electrophoreses and repairs on colored cables. The following characteristics of deficient color vision can lead to decisive errors GRAMBERG-DANIELSEN (10), SCHOBER (7).

1. In proto-deficient the maximum of brightness is displaced from 550 nm in the direction of 520 nm (i.e. to the violet end of the spectrum) in deutero-deficient in the direction of 580 nm.
2. The time-threshold for color sensitivity in deficient trichromates is longer in the range of the respective deficiency. In the case of dichromates the time-threshold in the red- and green-spectra may extend into the infinite.
3. The discriminative capability for intermediate color steps is considerably lower in dichromates than in normal trichromates. The trichromate is able to differentiate between 120 - 160 intermediate color steps, the protanope can identify approximately 27, the deuteranope only 17.
4. The spectrum in the red range is shortened for the protanope.
5. The foveal acuity is reduced corresponding to the extent of the proto-deficient in the red range of the spectrum.

That means that only trichromates may be accepted as payload-specialists and then only up to certain limits, since under given circumstances the proto-deficient will not perceive colors in the red range of the spectrum any longer. A reduction of the foveal acuity in a red range of 698 nm may take place in normal trichromates and deutero-deficient trichromates from 125% = 20/18 to an average of 70 % = 20/30, in proto-deficient trichromates, however, to 30 % or 40 %, provided the anomalous quotient (AQ) for these deficient subjects is not lower than 0.3. In subjects with a still lower AQ the visual acuity was even less, as shown in studies by GRAMBERG-DANIELSEN (10). An examination with anomaloscope will provide information as to type and degree of color-deficiency in such cases. Only scientists with an AQ between 0,3 and 5,0 should be admitted. It should always be kept in mind that a color deficient requires a larger area of stimulus, longer effective time and greater brightness than the normal subject. Thus a color-deficient is bound to make mistakes.

Another problem for the acceptance as payload-specialist is posed by glaucoma. In this context only the wide-angle glaucoma is of interest, since it does not cause any acute pressure increases. It is felt that the influence of weightlessness on the intraocular pressure in healthy subjects should be investigated during the first missions. If these examinations reveal, that there is no influence of weightlessness on the intraocular pressure, it is quite realistic to admit a scientist with a medicamentously treated glaucoma to space-flights, provided he has no disturbed vision resulting from medication. This is especially so since treatment may be continued throughout the mission. Instead of treatment with drops, subtarsal implantates could be used. Glaucomatous defects of the field of vision and optic nerve disturbances will be cause for rejection.

Subjects with disturbed eyelid closure, trichiasis, acute and chronic dacryocystitis, blepharitis and allergic conjunctivitis should not be admitted. These findings, which are not too aggravating on the ground, may considerably impair operational efficiency in space by causing susceptibility for blinding effects, epiphora and blepharospasm. In sensitive persons this is aggravated by the atmospheric conditions under which the tasks have to be performed. Odors caused by body gases have always been considered as highly disturbing in all space missions. Moreover, the constant airflow caused by air-conditioning will contribute to worsen the symptoms.

Acute and chronic keratitis or inflammations of the iris and the ciliary body must be considered a cause for disqualification because stress conditions may invite recurrence. Furthermore, all types of pigmentary degeneration of the retina must be excluded, because they are responsible for disturbances to the visual field and to dark adaptation. Healed chorioretinitis without disturbance of the centre and peripheral field of vision may be accepted.

Cause for rejection will be all cases involving neuroretinitis or a documented history of retrobulbar neuritis, papilledema and optic atrophy on the bases of their pathological genesis. Findings after injuries with anterior and posterior synechiae and dislocations and clinically evident subluxations of the lens are cause for disqualification, just as retained intraocular foreign bodies and tumors of the eye and the orbita.

What should be the policy with subjects having retinal degenerations and foramina of the retina, and what about successfully treated detachments?

Our observations of several thousand pilots in 1975, for example, revealed 438 degenerations of the peripheral retina with partly coagulated and partly untreated foramina. This collective includes 4 operated and coagulated detachments and the subjects concerned are still on flying status. Applied to payload-specialists this means that not each and every degeneration with a foramen or any treated detachment in the periphery of the retina constitutes a cause for rejection. On the contrary, he must be considered as fit after firm scarring on the provision that he has not incurred any considerable restriction in the field of vision. The G-loads to be expected in SPACELAB missions are considerably below those to which jet pilots are exposed daily and this is the reason why I feel such a man should not be rejected.

All deliberations in connection with the proposal of ophthalmological requirements for a payload-specialist should start by considering that the man, in spite of the anomalies cited above, will

1. not suffer any damages in orbital flight
2. perform his tasks in a proficient manner, and
3. not be able to resort to his anomalies as an excuse for faulty performance.

REFERENCES

1. SCHMIDTKE, H. u. SCHOBER, H.: Sehanforderungen bei der Arbeit. A.W. Gentner-Verl. Stuttgart
2. SCHOBER, H.: Anforderungen von Behörden und Berufen an das Auge. H. Kolbensteiner Verlag, Essen, 1957
3. SPACE SHUTTLE PROGRAM: PAYLOAD ACCOMMODATIONS, JSC 07700, Volume XIV Revision C (1974)
4. ERNO RAUMFAHRTTECHNIK GmbH: Untersuchung über Vorauswahl und zur Ausbildung von Nutzlast-Experten (1976)
5. BEWERSDORFF, A., HUTZ, U.: Rolle und Ziele der DFVLR bei der SPACELAB-Nutzung
6. HARTMANN, E.: Beleuchtung und Sehen am Arbeitsplatz Wilhelm Goldmann Verlag München (1970)
7. SCHOBER, H.: Das Sehen, Band I (1961), Band II (1964) VEB FACHBUCHVERLAG Leipzig
8. NATIONAL AERONAUTICS AND SPACE ADMINISTRATION MANNED SPACECRAFT CENTER HOUSTON, TEXAS: General Specification Lighting, Manned Spacecraft and Related Flight Crew Equipment, Functional Design Requirements for SC-L-0002, 1972
9. GIBSON, E.G.: SKYLAB 4 Crew Observations Proceeding of the SKYLAB Life Sciences Symposium (1974) Vol I/II JSC-09275 NASA TMX - 58154 (November 1974)
10. GRAMBERG-DANIELSEN, B.: Farbuntüchtigkeit und Beruf unter besonderer Berücksichtigung der Verkehrsberufe. Arbeitsmedizinische Fragen in der Ophthalmologie, Vol. 2, 2. Symp. Amsterdam 1968 (S. Karger, Basel/New York 1969)

DISCUSSION

G.Perdriel: Au cours des vols de l'espace, les astronautes américains et les cosmonautes russes, on fait état d'une perturbation de la vision des couleurs portant surtout sur la perception chromatique du bleu, dont la tonalité paraissait moins saturée. Il semble donc nécessaire d'exiger un sens chromatique normal chez les futurs expérimentateurs des missions spatiales, comme celles incluses dans les projet "Spacelab".

Contrairement à ce qui vient d'être dit, je pense qu'il est préférable de ne pas admettre les dyschromates et même les protanomaux.

Je serais heureux d'avoir votre avis à ce sujet.

F.Daumann: Difficulties as a result of the seemingly less saturated blue colour will mainly be encountered by persons having a blue-yellow colour deficiency. It is not intended to admit persons belonging to this group as Spacelab Scientists, since they will also experience deficiencies in the range of the green colour, moreover, the "General Specifications, Requirements for *Lighting, Manned Spacecraft and Related Flight Crew Equipment, Functional Design*" specifying Spacelab illumination do not provide for blue colours. Payload Specialists having a proto-deficiency of up to 0.3 and being deutero-deficient trichromates of up to 5.0 AQ with a small range of setting may, in my opinion, be accepted, because the illumination and luminance provided are fully adequate for their experiments and also because they are doing the same experiments on the ground; moreover, flying safety is not affected.

H.Oser: I think soft lenses cannot be applied during space flight, because of blood pooling in the head due to weightlessness. What do you think about that?

F.Daumann: This bloodpooling which I have called "headfullness" is only an obstacle to wearing contact lenses. This state, however, will not persist more than 14 days, so that in longer missions wearing of contact lenses is thinkable.

M.W.Whittle: On the same question of colour vision, I have understood that the object of having these fellow specialists in the shuttle program was to send into space the scientist most able to perform a particular experiment. If he is the world leader on that particular experiment on the ground, a colour vision defect is not a problem when doing this experiment in space. For the astronauts who fly the shuttle, you need a good colour vision, but I cannot understand this need for people who will perform in space the same experiment they do on the ground perfectly adequately.

F.Daumann: In principle I agree, if the specialist were only to conduct experiments in which he is the "world leader". As I have pointed out, however, he is confronted with additional tasks for which he indeed requires a more differentiated colour vision. The foregoing will not apply if the man is not charged with these tasks.

J.Chevaleraud: Dans un premier temps, je voudrais donner une réponse à l'intervention du Dr Whittle. A mon avis, les trichromates anormaux ne doivent pas être acceptés comme astronautes scientifiques. On sait en effet, qu'avec un éclairage insuffisant, comme un éclairage de secours par exemple, la vision des couleurs est différente. Dans de telles conditions, les trichromates anormaux pourraient être gênés et commetre des erreurs.

Dans un deuxième temps, je voudrais poser au Dr Daumann quatre questions:

(1) Quels moyens compte-t-il utiliser pour mesurer la vision stéréoscopique? Les matériels utilisés donnent en effet des éléments de réponse difficilement comparables d'une technique à l'autre.

(2) Quel type de lentilles cornéennes souples pense-t-il accepter? S'agit-il de lentilles minces ou de lentilles hydrophiles? Dans ce dernier cas à quel degré d'hydrophilie compte-t-il s'arrêter pour que ses sujets puissent supporter correctement leurs lentilles?

(3) Le Dr Daumann accepterait des sujets glaucomateux traités. S'agit-il d'un traitement médical, et dans ce dernier cas, quelles drogues compte-t-il accepter au rejeter? On sait en effet que la pilocarpine, par exemple, réduit le champ visuel et modifie l'acuité visuelle, la vision nocturne et la vision chromatique. Il ne semble donc pas que l'on puisse accepter un sujet porteur d'un glaucome traité par pilocarpine.

(4) A propos des sujets porteurs de dégénerescences rétiniennes ou de décollement de la rétine opérés, nous avons des cas semblables qui ont repris le vol une fois opérés. Quelle durée exigerait le Dr Daumann entre le moment où l'anomalie est détectée et traitée et le moment où il accepterait que les sujets volent?

F.Daumann: Ref.1 – to assess stereoscopic vision I believe the well-known "fly-test" to be adequate.

Ref.2 – I mentioned the problem of contact lenses pointing out related difficulties and also said that so far there are no investigations and experiences on wearing contact lenses in a state of weightlessness. I have also mentioned the problem of fluid-shifting within the first 14 days, hydrophilic lenses, in my opinion, are most suitable. Hydrophilic lenses available on the market having a hydrophilic degree between 50 and 60% could be used for this purpose.

Ref.3 – I have no objections whatsoever against a subject with a surgically treated glaucoma not requiring additional conservative therapy to let him fly along as scientist. We have several pilots flying after glaucoma surgery. I am well aware of the problems related to conservative glaucoma treatment and its disadvantages for the visual organs. There again it must be realized that the specialist on the ground has to perform the same type of work as awaits him in the Spacelab. I shall not commit myself on a definitive medication since all drugs have side effects to a greater or smaller degree. I have, however, stated as a prerequisite to admitting such specialists that preliminary examinations under a state of weightlessness must not reveal any negative influence on the intraocular pressure.

Ref.4 – The time at which flying clearance will be granted following treatment of retinal degenerations resp. retinal detachments depends on the respective findings. I would not clear a case involving a well-healed detachment before two months, but would permit resuming flying duties in a man with Laser coagulation of a retinal degeneration perhaps 14 days afterwards, provided there are no visible signs of local irritation.

ATHLETIC ENDURANCE TRAINING: ADVANTAGE FOR SPACE FLIGHTS ? THE SIGNIFICANCE OF PHYSICAL FITNESS FOR SELECTION AND TRAINING OF SPACELAB CREWS

K.E. Klein, M.D., H.M. Wegmann, M.D., and P. Kuklinski
Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt e.V.
Institut für Flugmedizin
Koelner Strasse 70
5300 Bonn - Bad Godesberg
F.R. Germany

SUMMARY

An intensive physical exercise training has been part of the conditions of astronauts and cosmonauts for spaceflights; however, its benefits have also been questioned. With respect to the significance of this problem for crew and passengers of future Spacelab missions we have reviewed the pertinent literature.

From the results it is concluded that the morphological and functional changes obtained with an athletic endurance training are rather specific, and not at all, of general advantage for the tolerance to space stresses. In particular during gravitational loads they allow a higher shift of fluid into the lower extremities with the possible consequence of a reduced tolerance. This response obviously, is accentuated through immersion and weightlessness; also, the aerobic work capacity is more impaired.

Therefore, the following *recommendations* are given:

1. Preflight, muscular and cardiovascular fitness, as evaluated best with maximal oxygen uptake, should be kept within the normal range given for a non-athletic population with relation to sex, age, and weight. Deviation from this range should be corrected by controlled training or deconditioning programs.

2. Inflight, it is of significance to preserve muscular as well as cardiovascular fitness. Apparently, the exercise program applied in Skylab 4 came close to an optimal solution with respect to exercise devices. A completion covering in particular the additional training of specific muscle groups seems necessary. The duration of daily exercise will depend on the duration of mission; a maximum of considerably less than one hour has been predicted. For short missions, as for instance the 7 days Spacelab missions, an even smaller amount of exercise should be sufficient.

INTRODUCTION

An intensive physical exercise training has been part of the preparation of astronauts and cosmonauts for space missions. In the conditioning program of both, the USA and the USSR, such a training "was emphasized as a nonspecific method for increasing resistance to the effects of most spaceflight factors" (26). In particular, it was assumed that the higher cardiovascular fitness as it is brought about by athletic endurance activities favours the adjustment to gravity changes. However, the benefits of an endurance training for the tolerance to environmental extremes have also been questioned (22, 23, 25, 35, 41; see also 29). Recently, there have been more indications that the functional and morphological consequences of a rigourous exercise training may not only be useless but even disadvantageous with respect to the responses to certain spaceflight related stressors.

It is the purpose of this paper to discuss the problem under the aspect of a training concept for future space crews, in particular for Spacelab, by reviewing own experimental results and pertinent data from the literature.

MATERIALS AND METHODS

The data presented concern the responses of athletes and non-athletes to altitude, acceleration, orthostasis, Lower Body Negative Pressure, and simulated weightlessness, and of astronauts to spaceflights. The results discussed here have been published before; where data and figures are reproduced from other sources, this is done with permission of the authors.

In all experiments reviewed, the group of "trained athletes" consisted of male subjects in the range of 20 to 34 years of age who regularly exercised in endurance sports like running, swimming, bicycling, etc. As the physiological criterion (3) of "physical fitness" the aerobic capacity ($\dot{V}O_2$max) during exhaustive exercise on a treadmill or bicycle ergometer was used. For further details the references quoted may be consulted.

RESULTS

Altitude (Hypoxia)

In 1966 our group studied 12 athletes (A) and 12 non-athletes (NA) comparatively under various loads, including exhaustive physical exercise, simulated altitude, acceleration, and orthostasis (21, 22, 25, 30, 40). The aerobic work capacity, $\dot{V}O_2$max, of A was 4.6 l/min or 65 ml/min/kg body weight; for NA it was 3.4 l/min or 44 ml/min/kg body weight. The difference of 35 % for the absolute, and of 50 % for the relative maximal oxygen uptake was highly significant (25).

In context with the topic of this paragraph the following results of this study are of interest: There was a reduction of the aerobic work capacity ($\Delta\ \dot{V}O_2max$) at 2 250 m simulated altitude of 0.46 l/min (= -10.1 % of sea-level $\dot{V}O_2max$) for A, and of 0.29 l/min (= -8.7 % of the sea-level $\dot{V}O_2max$) for NA; the higher reduction of athletes in altitude was again highly significant (30).

For the combined group of A and NA (n=24) Figure 1 shows the linear regression of the reduction of the aerobic capacity through simulated altitude on the aerobic capacity under control conditions; the positive correlation is also highly significant.

The suggestion that the higher aerobic capacity of a trained subject is more affected by a reduction in the environmental partial oxygen pressure, is strongly supported through Figure 2 in which the relative impairment of the sea-level $\dot{V}O_2max$ through altitude is shown separately for A and NA. The regression lines were computed from data reported in 15 different references on a total of 71 A and 78 NA who were studied in altitudes between 2 250 m and 4 300 m (30); they indicate for A a reduction of $\dot{V}O_2max$ of 11 % to 37 %, for NA a reduction of 6 % to 24 % with altitude increasing from 2 000 m to 5 000 m. It is, at least, of theoretical interest to note that if these regression equations are applied to the athletes and non-athletes of our study an equal $\dot{V}O_2max$ of 2.3 l/min is predicted for both groups at an altitude of 6 500 m. That means that the original sea-level difference of 1.2 l/min of the maximum oxygen uptake will be reduced to zero at 6 500 m.

Acceleration

The groups of athletes and non-athletes studied in simulated altitude we have also exposed to $+G_z$-forces on a centrifuge. With a rate of onset of 0.07 g/sec the Central Light Loss (CLL) occurred in the relaxed subjects, on average, at 6.89 $+G_z$ in A and 6.84 $+G_z$ in NA. The minimal difference was not significant; so was the correlation coefficient of r = -0.41 between CLL and the aerobic capacity of subjects (22). The corresponding line of regression is presented in Figure 3. These results as well as those of Cooper and Leverett (10) strongly suggest that the higher cardiovascular fitness gained through an athletic endurance training has no significant effect on the $+G_z$-tolerance. Instead, it was shown that CLL correlates negatively with the height of the blood-column determining the hydrostatic pressure difference between the heart and the eye, and positively with the prestress arterial blood pressure (22). On the other hand, the findings do not exclude that g-tolerance may be better if specific muscle groups were trained and their higher strength is made use of under g-loads.

Orthostasis

During a 20-min head-up 90° vertical tilt, 5 out of our 12 A and 4 out of our 12 NA fainted. At the same time some cardiovascular responses to tilting, like the more pronounced decrease of pulse pressure, were less advantageous in A than in NA. In the same sense the correlation between the pulse pressure during tilt and the aerobic capacity was negative (Figure 4, lefthand side). Since none of the differences and correlations was statistically significant (21) we concluded on an independency of orthostatic tolerance from physical fitness.

However, Luft et al. (27) have recently studied 5 A and 5 NA during Lower Body Negative Pressure (LBNP) with the same trend in their results but significant differences. The aerobic work capacity in comparison to our findings was lower in both groups; it was 3.5 l/min or 50 ml/min/kg body weight for A, and 2.9 l/min or 34 ml/min/kg body weight for NA. On the other hand, with 22 % for the absolute capacity and with 47 % for the relative magnitude of $\dot{V}O_2max$ the differences were comparable in size to those observed by us.

During LBNP the tolerance was figured out by adding up the products of negative pressure and time of exposure, thus taking into account the level of negative pressure as well as the duration of the test. This figure was 527 Torr x min in A, and 913 Torr x min in NA; the difference of 42 % in favour of NA was highly significant. Figure 4 demonstrates on the righthand side for the total of both groups the dependency of LBNP-tolerance on the aerobic capacity, as it was computed from the data of these authors. The negative correlation coefficient of r = -0.60 was also significant.

In their study Luft et al. (27) have also looked into the responses of limb volume to LBNP. They came to the conclusion that the legs of A seem to have "a greater tendency to accommodate fluids under LBNP stress" than those of NA. Through a highly significant correlation between the LBNP-tolerance and the total limb compliance, defined as per cent change in limb volume per unit LBNP x time, they were able to prove that a low tolerance is associated with a high compliance. At the same time they computed for their groups a significantly greater leg compliance in A, and related this to the greater susceptibility of A to LBNP. We have used the data of these authors and computed the regression of total limb compliance on $\dot{V}O_2max$. The result is presented in Figure 5; the negative correlation is highly significant.

Simulated Weightlessness (Immersion)

Already in 1969 Stegemann et al. (35) reported on a greater reduction of $\dot{V}O_2max$ in A than in NA as consequence of a 6-hours water immersion. From the data published in their paper we have computed the linear regression of the reduction of $\dot{V}O_2max$ on the prestress aerobic capacity; it is presented in the upper part of Figure 6; the positive correlation

is highly significant. Similarly as for altitude the dependency proves the higher sensitivity to immersion of the individual with a greater cardiovascular and muscular fitness.

At the same time the authors found that after immersion all endurance trained athletes (n=4) fainted during a 10-min vertical tilt showing symptoms of a vagovasal syncope while the untrained subjects (n=4) tolerated the tilt without abnormal effects. Recently, the greater orthostatic intolerance of athletes after immersion was confirmed with a greater number of subjects (36). In this study it was also shown that intermittent swimming exercise during immersion improves the circulatory responses during subsequent tilt table tests, however, again in NA clearly more so than in A.

To attain a quantitative measure of the cardiovascular responses the authors have used the "orthostatic index" of Burkhart and Kirchhoff (8) in which a lower value indicates a better tolerance. In the lower part of Figure 6 the change of this index is shown for A and NA, before and after immersion, with and without exercise. None of the untrained subjects collapsed during tilt. But without exercise the change of the orthostatic index indicated a deterioration of the tolerance as consequence of immersion.Since three out of four trained subjects collapsed after immersion without exercise, an orthostatic index could not be computed for this group. Through intermittent exercise the number of those athletes who collapsed was reduced to three out of eleven; in the remaining eight the increase of the orthostatic index indicated still an impairment of circulatory responses during tilt.

Spaceflight

The Proceedings of the Skylab Life Science Symposium (20) contain information on the individual responses of astronauts to spaceflights. In particular, the figures relating to the Skylab 4 crew give a good opportunity to evaluate the results under the topic of this paper. We have summarized in Table 1 those cardiovascular parameters of the three members of this mission which are of interest in this context. In doing so we have either directly adapted figures from the quoted references, or have computed derivatives from the data given there; the latter are often approximations.

Preflight findings: From the preflight values it is obvious that there were considerable differences in the grade of physical fitness between the crew members. Based on the last preflight estimation, i.e. four days before launch, the $\dot{V}O_2$max of the Scientist Pilot (SPT) and the Pilot (PLT) are 23 % and 18 %, respectively, higher than that of the Commander (CMD). (The differences were even more pronounced when the highest values within the last year before launch are compared (31): CMD = 40.0 ml/min/kg, SPT = 51.9 ml/min/kg, PLT = 57.0 ml/min/kg). If the aerobic capacity of the Skylab 4 crew is related to that of a large non-athletic population of comparable age (18) the $\dot{V}O_2$max of the CMD is about 2.5 % lower, that of the SPT and PLT 12 % and 18 %, respectively, higher. A similar differentiation becomes obvious with the maximal oxygen pulse. According to the Cooper-Scale (9) the CMD must be classified as of "fair" fitness, the SPT and PLT, however, as having a "good" to "excellent" level of physical fitness, depending on which of the preflight evaluations the classification is based.

Also, in the left ventricular mass and volume, as well as in the stroke volume, SPT and PLT showed pronounced signs of physical endurance activities. It was interpreted as the consequence of a much longer distance running during preflight training (17).

In view of the above quoted findings of Luft et al. (27) during LBNP on runners and non-runners it is remarkable also, that already in the LBNP-test before the flight the calf volume and heart rates increased considerably more in the two physically better trained crew members (19).

Inflight findings: During the mission the SPT and PLT clearly demonstrated poorer responses to provocative gravitational stress: A higher increase of heart rate and calf volume, and a greater reduction of pulse pressure during LBNP (19). In this respect, the responses of the SPT seem even "weaker" than those of the PLT. This interpretation is supported by the number of syncopes and presyncopes occurring during LBNP in the individual crew members: CMD = 1, SPT = 4, PLT = 2 (19). The additional observation of a higher vascular compliance during venous occlusion of the PLT, and even more so of the SPT has initiated the suggestion of an "anatomical difference in the CMD's deep venous structure" (37). In view of the findings with athletes and non-athletes presented before, this difference can also be seen in relation with physical fitness. (The graphic representation of the change of compliance as observed by Thornton et al. (37) is reproduced in Figure 7).

The $\dot{V}O_2$max and the oxygen pulse increased for about 10 - 15 % in all three crew members (28). Under normal conditions one would interprete these changes as an increment of the aerobic capacity due to the intense physical exercise training during flight. However, against this opinion it has been argued with good reason (4) that first, under zero-g a higher workload than during one-g will be possible without training because of an increased cardiac output caused by a higher central blood volume, and second, the necessary higher engagement of the arms during ergometer work in weightlessness contributes to the observed increment of $\dot{V}O_2$max. The finding of a higher arterial leg blood flow in weightlessness (37) and an increase of stroke volume for about 30 % during immersion (1) speaks, indeed, in favour of the first of these arguments. Also, the increase of 10 - 15 % in $\dot{V}O_2$max already at the first inflight test, and a "slight downward trend during the latter part of the mission" (31) make an interpretation as training effect difficult.

Postflight findings: A comprehensive evaluation of the Skylab results leaves no doubt that inflight physical training had a positive effect on postflight cardiovascular responses: The length of time required for normalization was inversely related to the amount of exercise performed inflight (28).

But heart rate responses during postflight LBNP stress indicate again a higher degree of orthostatic intolerance in the SPT and PLT than in the CMD; in spite of the fact that quantitative personal exercise was lowest in the CMD. Also the leg volume during LBNP was elevated against the preflight values in the SPT and PLT, only. So, it seems in agreement with findings after immersion that physical exercise was more successful in the less trained individual in attenuating the decremental consequences of weightlessness on orthostatic tolerance.

With respect to the general criteria of physical fitness it is of interest to note, that during the first ten postflight days there was a mean reduction in the left ventricular mass and volume of about 10 % to 12 % also in SPT and PLT, only; at the same time the stroke volume at rest decreased for 18 % to 19 % in SPT and PLT, but not in the CMD. Henry et al. (17) have already mentioned the possibility that these changes "reflect the inability (of trained runners) to continue distance running while in space". Unfortunately, $\dot{V}O_2max$ does not seem to have been measured.

If we interprete the findings in terms of the comparison of athletes and non-athletes they suggest the following conclusion: First, the trained subjects in weightlessness (as in immersion and altitude), absolutely and relatively, lose more of their higher fitness, and second, physical exercise training in space is more effective in the relatively untrained subject in reducing the deteriorating effect of weightlessnes on fitness.

There is, however, one observation which does not fit very well into the picture drawn so far from the more favourable responses of untrained subjects: All Skylab crew members except for the Skylab 4 SPT and PLT, exhibited a relatively extensive reduction in both stroke volume and cardiac output during postflight submaximal exercise; it was accompanied by a higher AV-oxygen difference (28). This finding hardly can be interpreted in relation to preflight physical fitness since $\dot{V}O_2max$ was similar for instance in Skylab 3 SPT and Skylab 4 PLT, and was even higher in Skylab 3 PLT than in Skylab 4 SPT and PLT (31). But also inflight quantitative personal exercise does not explain the difference in postflight stroke volume because the daily average for instance was exactly the same in Skylab 3 and Skylab 4 PLT and was only about 10 % higher on average in the Skylab 4 crew as against Skylab 3 (28).

DISCUSSION

From the data presented it seems most likely that the higher cardiovascular and muscular fitness obtained with a regular athletic endurance training has a questionable or unfavourable effect on the tolerance to some environmental extremes. From these, the responses to gravitational stress are of particular operational interest in manned spaceflights.

Vertical tilt, LBNP and $+G_z$-acceleration result in an increased bloodflow to the lower extremities with an increment in venous pressure, an extension of the veins and a pooling of blood. Subsequently, there is a reduction in the circulating blood-volume and in venous return with the consequence of a diminuation of the stroke volume. This initiates a sympathetic stimulation with a rise in catecholamine excretion and an increase in heart rate and vascular tone. It is now of interest to discuss which of the morphological and functional changes occurring with physical training could be responsible for the differences in the tolerance of athletes to gravitational loads.

Stegemann et al. (34) have demonstrated that the blood pressure control system in endurance trained athletes is less "effective" in the sense of smaller heart rate and blood pressure responses induced by the baroceptors through a change in the transmural pressure. At the same time, at a given exercise load, the sympathetic activation in athletes is less pronounced and the noradrenaline level in blood lower (Trap-Jensen, quoted after (18), p. 442). Smaller responses of this kind are favourable for dynamic exercise: The higher heart- and blood-volume of athletes allow a higher stroke volume as long as muscular contractions secure venous return. Therefore, heart rates may be kept lower at given work loads, and the limitation of the aerobic capacity through the cardiovascular system is shifted to higher exercise intensities. However, during gravitational stress the attenuation of the control system may prevent circulatory responses necessary to maintain a sufficient cerebral blood flow.

During physical exercise training the vascularisation in the muscle is enlarged (18, pp. 307-311). This is one of the premises for a higher local oxygen uptake and efficiency of the muscle. With an increase of the capillary pressure the enlarged vascular bed allows a greater accommodation of fluid, as was proven by the higher compliance of athletes during LBNP (27).

There is one striking difference between the results obtained with LBNP on the one hand, where all athletes showed signs of vagovasal syncopes, and vertical tilt and acceleration, on the other, where there was also negative but low and insignificant correlation between tolerance criteria and physical fitness (22). We believe that these differences can be explained best by the more consequent muscular inactivity of subjects possible with LBNP. The contraction of muscles is one effective countermeasure against the pooling of blood in the lower extremities: It compresses veins and pumps blood toward the heart, thus improving venous return and enlarging stroke volume. The more this action can be

TABLE 4. STANDARD DEVIATIONS

Mercury Apollo

avoided the more the relatively unfavourable cardiovascular responses of physically trained subjects to gravitational stress become fully effective.

Immersion, like weightlessness,increases the tendency towards orthostatic intolerance. This process and the different factors contributing to it have been reviewed recently by Gauer (13). Only those aspects relating to the topic of this paper will be repeated, here.

Due to the change in hydrostatic pressure during immersion there is a shift of blood into the thorax with an increase of heart-volume, and central venous and transmural pressure. Through the, meanwhile, well known fluid volume control described by Gauer and Henry (14) the urinary excretion is stimulated and a decrease of blood- and plasma-volume initiated. There can be no doubt that these processes contribute to the orthostatic intolerance and the reduction of work capacity observed after immersion and spaceflights. However, the extent of blood- and plasma-volume reduction during simulated weightlessness is not significantly different between athletes and non-athletes (27, 28), and therefore, can hardly explain the different impairment of gravitational tolerance of these two groups.

The centralization of blood initiates a decrease in the peripheral venous tone (12) and a vasodilatation of the muscular vessels (1). The dependency of these changes from physical fitness has not been examined, yet. However, one could take the higher compliance during venous occlusion observed in space in those crew members of Skylab 4 with the higher aerobic capacity (37) as an indication of the fitness-dependency of the decrease in venous tone.

Altogether, the vegetative nervous system seems to play a significant role in the orthostatic tolerance. Not only the circadian rhythm of cardiovascular responses to tilt (2, 24) supports this idea, but also a further analyzation of the cardiovascular system's responses to weightlessness and immersion. One of the first effects of physical exercise training is the shift to a higher trophotropic influence with a decrease of heart rate, an increase of the duration of heart-systole and -diastole,and a reduction of catecholamine release. Obviously, this tendency is intensified during immersion: There is not only a general diminution of the noradrenaline release (16), but sympathetic activation and vanillylmandelic acid excretion occurred distinctly less in athletes as compared to non-athletes (33). In addition, an inhibition of the vagal influence by oral application of atropine was successful in completely abolishing the syncopes in athletes after immersion (35). It is obvious, that immersion and weightlessness lead to an accentuation of those properties of the trained organism which allow a comparatively higher shift of fluid during gravitational stress into the lower extremities already under normal conditions: The legs are not only of little use and of disadvantage in space (32), but they become more so after vigorous physical endurance training before the flight.

An explanation for the higher reduction of work capacity of athletes through immersion and weightlessness is much more difficult since the decrease in blood- and plasma-volume was not significantly different in both groups, as mentioned above. If at all, there was, rather, a tendency towards a somewhat higher change of these volumes in untrained subjects after immersion (5, 39) and during LBNP (27).

The more pronounced impairment of the aerobic capacity of athletes therefore speculatively has been related to the metabolism of the muscle cell: It was supposed that aldosterone was involved in ATP-formation and argued that the lower level period (33) could be responsible for a higher reduction in maximum oxygen uptake of the muscle (6). It requires further experimental research to confirm these ideas.

Finally, it may be mentioned that the problem discussed in principle is already well known in sports medicine: A sudden disruption of training causes the so called "acute relaxation syndrome"; some symptoms being similar to those observed after weightlessness. The syndrome is the more pronounced the higher the status of physical training, i.e. the higher $\dot{V}O_2$max. As a conclusion from this knowledge, it seems also not logical to build up a high status of physical fitness during the preflight phase with the consequence of being forced to maintain it in weightlessness by a high level of physical exercise in order to reduce the intensity of symptoms after return to gravity. Obviously, for this reason preflight deconditioning was induced by a planned reduction in personal exercise for the first time in one member of the Skylab 4 crew (7, 31).

CONCLUSION

The knowledge of the muscular and cardiovascular deconditioning in weightlessness is still incomplete. In space, studies will be necessary on humans which have no other assignments than being an experimental subject. However, the data already collected in space, together with those obtained from simulation experiments allow conclusions with respect to the topic of this paper.

1. For space crews preflight physical fitness as evaluated by maximum oxygen uptake should be in the normal range given for a non-athletic population with relation to sex, age, and weight. If it is lower it should be increased through a physical exercise training. In this context swimming could be a more appropriate activity than running, since it does not preferentially use the legs and involves other muscle groups to a greater extent. In addition, swimming may have the advantage of initiating adaptation processes typical for the hypogravic environment. Further investigations are required on this field.

If physical fitness is higher than normal a controlled detraining or deconditioning program should be applied. This will take several months depending on the state of fitness at the selection.

2. Inflight, it is of significance to preserve muscular as well as cardiovascular fitness. In addition, activity with larger muscle groups gives relief from the feeling of headfullness (15) experienced during weightlessness. Apparently, the exercise program applied in Skylab 4 came close to an optimal solution with respect to exercise devices. A completion with an additional training of some muscle groups not covered so far, seems necessary. The duration of daily exercise will depend on the duration of mission; a maximum of "considerably less than one hour" (38) has been predicted. In view of the time course of the development of symptoms (11),for short flights, as for instance the 7 days Spacelab missions, a duration of 20 - 30 min per day should be sufficient. Eventually, postflight deconditioning symptoms that transiently occur can be controlled by an appropriate medication, if necessary.

REFERENCES

1. Arborelius, M., U.J. Balldin, B. Lilja, and C.E.G. Lundgren. 1972. Hemodynamic Changes in Man during Immersion with the Head above Water. Aerospace Med. 43:592-598.

2. Aschoff, J.H., and J. Aschoff. 1969. Tagesperiodik der orthostatischen Kreislaufreaktion. Pflügers Arch. 306:146-152.

3. Atha, J. 1974. Physical Fitness Measurements. In: L.A. Larson (Ed.): Fitness, Health, and Work Capacity. International Standards for Assessment. New York: MacMillan Publ. Co.Inc., Part III, 470-487.

4. Bergmann, St.A., G.W. Hoffler, and R.L. Johnson. 1974. Evaluation of the Electromechanical Properties of the Cardiovascular System. In: The Proceedings of the Skylab Life Sciences Symposium. JSC-09275, NASA TM X-58154. Houston: National Aeronautics and Space Administration, Vol. II:681-711.

5. Boening, D., H.V. Ulmer, U. Meier, W. Skipka, and J. Stegemann. 1972. Effects of a Multi-Hour Immersion on Trained and Untrained Subjects: I. Renal Function and Plasma Volume. Aerospace Med. 43:200-305.

6. Boening, D. 1974. Einige physiologische Auswirkungen mehrstündigen Aufenthaltes in Wasser und ihre Abhängigkeit vom Trainingszustand. In: Kölner Beiträge zur Sportwissenschaft 3, Jahrbuch der Deutschen Sporthochschule Köln 1974. Schorndorf: Hofmann Verlag, 7-14.

7. Burchard, E.. 1975. Erfahrungen bei Auswahl und Training von Astronauten für das Skylab- und Apollo-Soyuz-Programm. 14. Jahrestagung der Deutschen Gesellschaft für Luft- und Raumfahrtmedizin. Porz-Wahn/Germany, 11-12 November.

8. Burkhart, K., and H.W. Kirchhoff. 1966. Zur Beurteilung der orthostatischen Toleranz. Wehrmedizin 4:89-99.

9. Cooper, K.H. 1968. A Means of Assessing Maximum Oxygen Intake. J.Amer.Assoc. 203: 201-204.

10. Cooper, K.H., and S. Leverett. 1966. Physical Conditioning Versus $+G_z$ Tolerance. Aerospace Med. 37:462-465.

11. Dietlein, L.F. 1974. Skylab: A Beginning. In: The Proceedings of the Skylab Life Sciences Symposium. JSC-09275, , NASA TM X-58154. Houston: National Aeronautics and Space Administration. Vol. II; 795-814.

12. Echt, M., L. Lange, and O.H. Gauer. 1974. Changes of Peripheral Venous Tone and Central Transmural Venous Pressure during Immersion in a Thermo-Neutral Bath. Pflügers Arch. 352:211-217.

13. Gauer, O.H. 1975. Recent Advances in the Physiology of Whole Body Immersion. Acta Astronautica 2:21-39.

14. Gauer, O.H., and J.P. Henry. 1963. Circulatory Basis of Fluid Volume Control. Physiol. Review 43:423-481.

15. Gibson, E.G. 1974. Skylab 4 Crew Observations. In: The Proceedings of the Skylab Life Sciences Symposium. JSC-09275, NASA TM X-58154. Houston: National Aeronautics and Space Administration. Vol. I:47-54.

16. Goodall,Mc.C., M. McCally, and D.E.Graveline. 1964. Urinary Adrenaline and Noradrenaline Response to Simulated Weightlessness State. Am.J.Physiol. 206:431-436.

17. Henry, W.L., St.E. Epstein, J.M. Griffith, R.E. Goldstein, and D.R. Redwood. 1974. Effect of Prolonged Space Flight on Cardiac Function and Dimensions. In: The Proceedings of the Skylab Life Sciences Symposium. JSC-09275, NASA TM X-58154. Houston: National Aeronautics and Space Administration. Vol. II:711-721.

18. Hollmann, W. und Th. Hettinger. 1976. Sportmedizin - Arbeits- und Trainingsgrundlagen. Stuttgart-New York: Schattauer Verlag.

19. Johnson, R.L., G.W. Hoffler, A.E. Nocogossian, S.A. Bergman, and M.M. Jackson. 1974. Lower Body Negative Pressure: Third Manned Skylab Mission. In: The Proceedings of the Skylab Life Sciences Symposium. JSC-09275, NASA TM X-58154. Houston: National Aeronautics and Space Administration. Vol. II:545-595.

20. Johnston, R.S., L.F. Dietlein (Edts.). 1974. The Proceedings of the Skylab Life Sciences Symposium. Vol. I and II. JSC-09275, NASA TM X-58154. Houston: National Aeronautics and Space Administration.

21. Klein, K.E., F. Backhausen, H. Brüner, J. Eichhorn, D. Jovy, J. Schotte, L. Vogt und H.M. Wegmann. 1968. Die Abhängigkeit der Orthostase- und Beschleunigungstoleranz von Körperbau und Leistungsfähigkeit. Int.Z.angew.Physiol.einschl.Arbeitsphysiol. 26:205-226.

22. Klein, K.E., H. Brüner, D. Jovy, and H.M. Wegmann. 1969. Influence of Stature and Physical Fitness on Tilt-Table and Acceleration Tolerance. Aerospace Med. 40:293-297.

23. Klein, K.E., H. Brüner, E.D. Voigt, and H.M. Wegmann. 1966. Comparative Studies on Physiological Indices of Fitness in Man under Exercise, Low Pressure and Acceleration. In: H. Yoshimura, and S. Weiner (Edts.): Human Adaptability and its Methodology. Tokyo: Japan Soc. Prom. Sci., 234-247.

24. Klein, K.E., H.M. Wegmann, and H. Brüner. 1968. Circadian Rhythm in Human Performance, Physical Fitness and Stress Resistance. Aerospace Med. 39:512-518.

25. Klein, K.E., H.M. Wegmann, H. Brüner, and L. Vogt. 1969. Physical Fitness and Tolerances to Environmental Extremes. Aerospace Med. 40:998-1001.

26. Link, Mae M., and N.N. Gurovskiy. 1975. Training of Cosmonauts and Astronauts. In: M. Calvin and O.G. Gazenko (Edts.): Foundations of Space, Biology and Medicine. Washington: National Aeronautics and Space Administration, Vol. III:438-450.

27. Luft, U.C., L.G. Myhre, J.A. Loeppky, and M.D. Venters. 1976. A Study of Factors Affecting Tolerance of Gravitational Stress Stimulated by Lower Body Negative Pressure. Research Report on Specialized Physiological Studies in Support of Manned Space. Contract NAS 9-14472. Albuquerque: Lovelace Foundation, 2-60.

28. Michel, E.L., J.A. Rummel, C.F. Sawin, M.C. Buderer, and J.D. Lem. 1974. Results of Skylab Medical Experiment, M 171-Metabolic Activity. In: The Proceedings of the Skylab Life Sciences Symposium. JSC-09275, NASA TM X-58154. Houston: National Aeronautics and Space Administration. Vol. II:722-776.

29. Pestov, J.D., and S.J. Gerathewohl. 1975. Weightlessness. In: M. Calvin and O.G. Gazenko (Edts.): Foundations of Space Biology and Medicine. Washington: National Aeronautics and Space Administration, Vol. II, Book 1, 305-354.

30. Rimpler, A. 1970. Der Einfluß des Trainingszustandes auf die körperliche Leistungsfähigkeit in der Höhe. DLR-FB 70-08. München: ZLDI.

31. Sawin, C.F., J.A. Rummel, and E.L. Michel. 1975. Instrumented Personal Exercise During Long-Duration Space Flights. Aviat. Space Environm. Med. 46:394-400.

32. Shephard, J.T. 1974. Contribution to the Panel Discussion. In: The Proceedings of the Skylab Life Sciences Symposium. JSC-09275, NASA TM X-58154. Houston: National Aeronautics and Space Administration. Vol. II:819-823.

33. Skipka, W., D. Boening, K.A. Deck, K.A. Meurer, and W.R. Külpmann. 1975. Endocrine Reactions of Athletes and Non-Athletes during Immersion. Pflügers Arch. 359, R 138.

34. Stegemann, J., A. Busert, and D. Brock. 1974. Influence of Fitness on the Blood Pressure Control System in Man. Aerospace Med. 45:45-48.

35. Stegemann, J., H.D. Fraening, and M. Schiefeling. 1969. Der Einfluß einer 6-stündigen Immersion in thermoindifferentem Wasser auf die Regulation des Kreislaufs und die Leistungsfähigkeit bei Trainierten und Untrainierten. Pflügers Arch. 312:129-138.

36. Stegemann, J., U. Meier, W. Skipka, W. Hartlieb, B. Hemmer, and U. Tiebes. 1975. Effects of a Multi-Hour Immersion with Intermittent Exercise on Urinary Excretion and Tilt Table Tolerance in Athletes and Nonathletes. Aviat.Space and Environm. Med. 46:26-29.

37. Thornton, W.E., and G.W. Hoffler. 1974. Haemodynamic Studies of the Legs under Weightlessness. In: The Proceedings of the Skylab Life Sciences Symposium. JSC-09275, NASA TM X-58154. Houston: National Aeronautics and Space Administration, Vol. II: 623-635.

38. Thornton, W.E., and J.A. Rummel. 1974. Muscular Deconditioning and its Prevention in Space Flight. In: The Proceedings of the Skylab Life Sciences Symposium. JSC-09275, NASA TM X-58154. Houston: National Aeronautics and Space Administration, Vol. I: 403-416.

39. Ulmer, H.V., D. Boening, J. Stegemann, U. Meier und W. Skipka. 1972. Pulsfrequenz, Blutdruck, Blutvolumen und Sauerstoffaufnahme von Ausdauer-Sportlern und Nichtsportlern während Immersion in Wasser. Zschr. Kreislaufforschung 61:934-946.

40. Uthoff, J. 1969. Das Verhalten von Leistungskriterien bei körperlicher Arbeit im Sauerstoffmangel - Untersuchungen an Hochleistungssportlern. DLR-FB 69-41. München: ZLDI.

41. Wegmann, H.M., and K.E. Klein. 1970. Physical Training Status in Relation to Stress Tolerances. In CP No. 81: On Physical Fitness in Flying. Paris: NATO-AGARD, 5-1 to 5-9.

Table 1: Individual Characteristics of Physical Fitness and LBNP-Tolerance of SKYLAB 4 Crew

	CMD	SPT	PLT	Remark	Ref.
PREFLIGHT					
$\dot{V}O_2$max (ml/min/kg)	40.0	48.9	47.0		(28)
Left ventr.mass^{+} (grams)	250	330	275		(17)
Left ventr.vol.at end diastole^{+} (ml)	130	185	175		(17)
Stroke vol.$^{+}$ (ml/beat)	100	136	140		(17)
Calf volume^{++} (%-change)	2.4	3-4	3-4		(19)
INFLIGHT					
Heart rate^{++} (beats/min)	11.8	37.2	27.9	resting vers. stressed	(19)
Heart rate^{++} (beats/min)	12.2	36.7	26.7	mean infl.vers.prefl.	(19)
Pulse pressure^{++} (mmHg)	7.1	-6.1	-2.8	mean infl.vers.prefl.	(19)
Calf volume^{++} (%-change)	5-7	8-11	8-11	mean inflight	(19)
Vascul.compliance Change^{+++} (vol.%)	2.0-2.5	4.0-5.0	3.5-4.0	range of mean responses	(37)
	(2.5)	(7.0)	(5.5)	(max. response)	
POSTFLIGHT					
Heart rate^{++} (beats/min)	11.9	27.9	26.8	resting vers. stressed recovery +1	(19)
Left ventr.mass^{+} (grams)	250	300	250	mean: day 1-10	(17)
(%-change)	(±0)	(-10)	(-9)	(prefl.vers.postfl.)	
Left ventr.vol.at end diastole^{+} (ml)	130	160	155	mean: day 1-10	(17)
(%-change)	(±0)	(-13)	(-12)	(prefl.vers.postfl.)	
Stroke vol.$^{+}$ (ml/beat)	100	110	115	mean: day 1-10	(17)
(%-change)	(±0)	(-19)	(-18)	(prefl.vers.postfl.)	

$^{+}$ at rest; $^{++}$ LBNP: -50mmHG; $^{+++}$ ven.occl.: 30mmHg

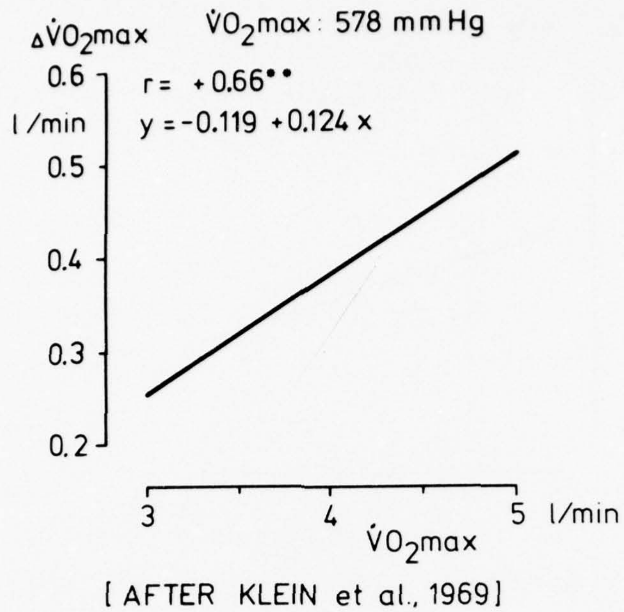


FIGURE 1 LINEAR REGRESSION OF PHYSICAL FITNESS [$\dot{V}O_2$MAX] REDUCTION AT SIMULATED ALTITUDE ON SEA LEVEL PHYSICAL FITNESS (22)

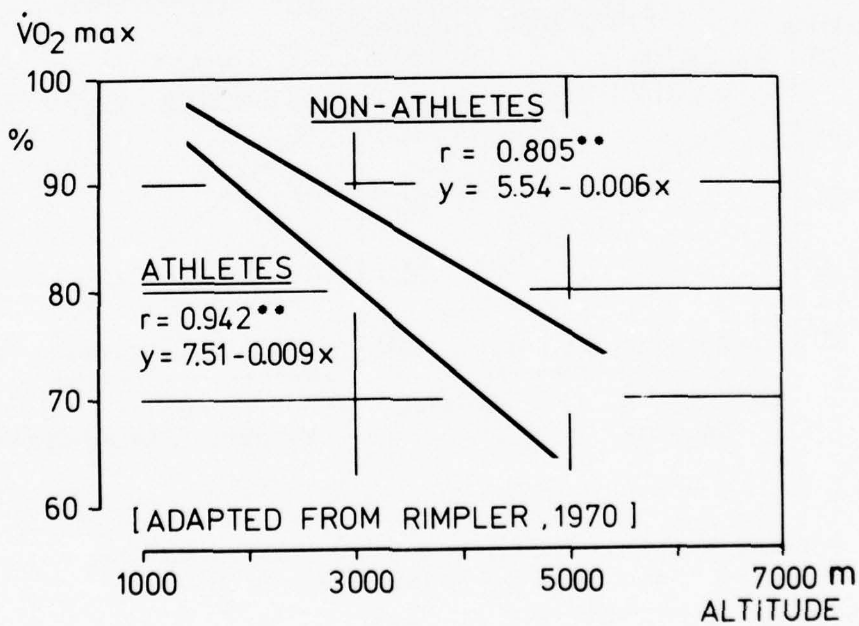


FIGURE 2 THE REDUCTION OF PHYSICAL FITNESS [$\dot{V}O_2$MAX] WITH ALTITUDE: LINEAR REGRESSION IN ATHLETES AND NON-ATHLETES (30)

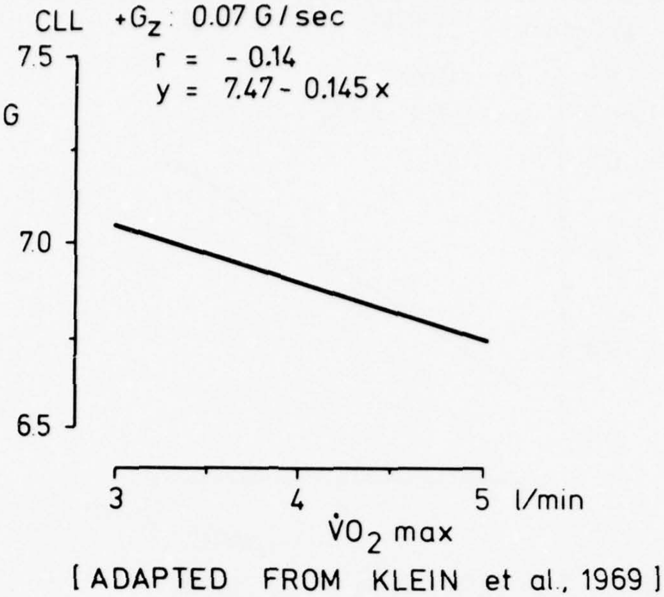


FIGURE 3 LINEAR REGRESSION OF +G_Z-TOLERANCE ON PHYSICAL FITNESS [$\dot{V}O_2$MAX] (22)

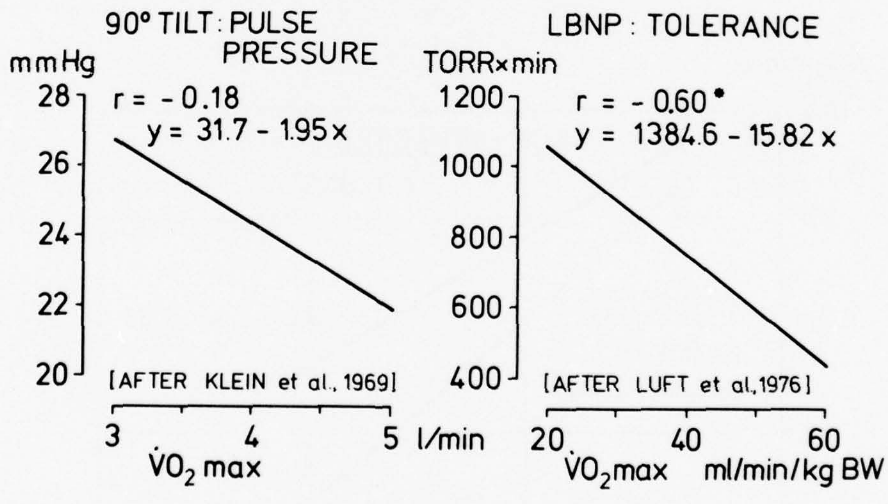


FIGURE 4 LINEAR REGRESSION OF PULSE PRESSURE RESPONSE TO TILTING AND OF LBNP-TOLERANCE ON PHYSICAL FITNESS [$\dot{V}O_2$MAX] (22, 27)

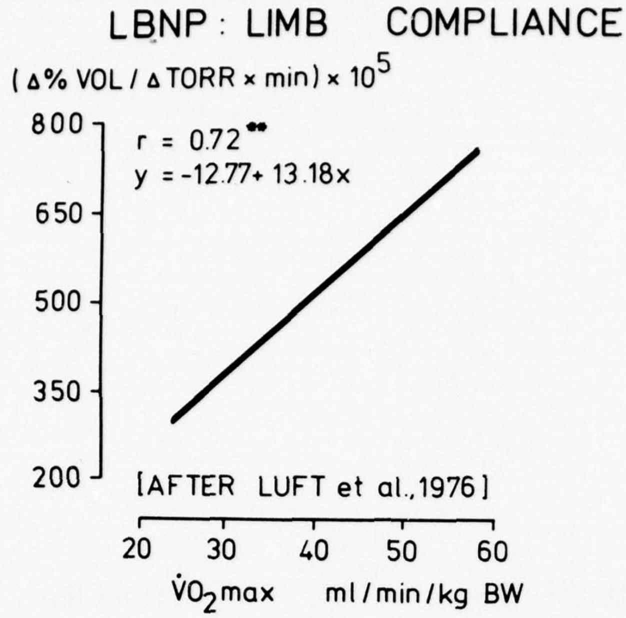


FIGURE 5 LINEAR REGRESSION OF LIMB COMPLIANCE ON PHYSICAL FITNESS [$\dot{V}O_2$MAX] (27)

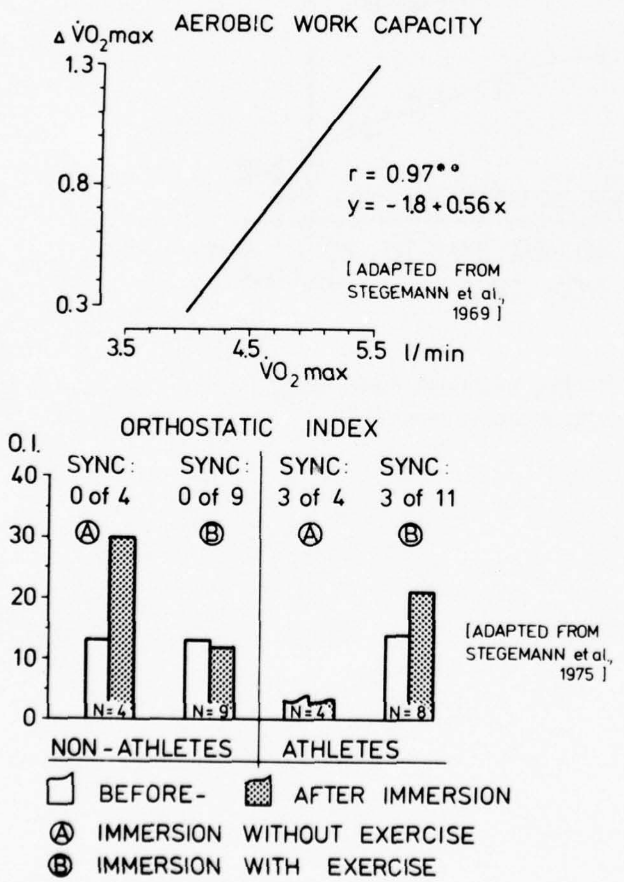


FIGURE 6

LINEAR REGRESSION OF PHYSICAL FITNESS [$\dot{V}O_2$MAX] REDUCTION ON PRESTRESS PHYSICAL FITNESS AND ORTHOSTATIC TOLERANCE IN ATHLETES AND NON-ATHLETES AFTER IMMERSION (35, 36)

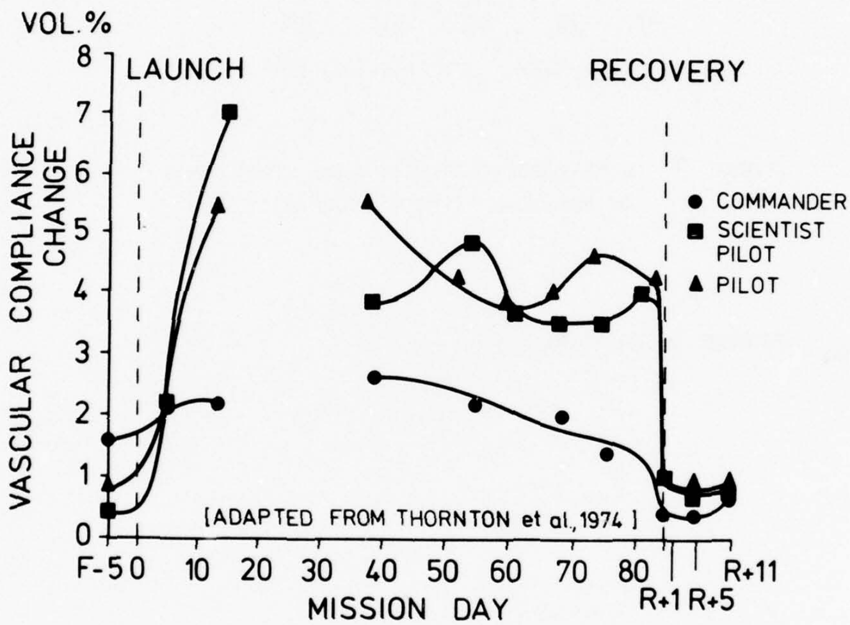


FIGURE 7 SKYLAB 4 CREW VASCULAR COMPLIANCE DURING VENOUS OCCLUSION (37)

DISCUSSION

M.W.Whittle: I would like to congratulate Dr Klein on an excellent contribution. Working with the astronauts during Skylab, I became convinced that there were two pieces of "mythology" present among the astronaut corps. First, that physical training gave you protection against the deconditioning effects of zero-g, and, secondly, that acrobatic flight gave you some protection against the vestibular effects. I am convinced that both are incorrect, but have no evidence for this opinion. Dr Klein has now produced some good data and theories to counter the first piece of "mythology", and I hope that workers in the vestibular field will confirm my impressions there as well. But how are we going to convince the astronauts?

K.E.Klein: Since the Spacelab payload specialists we will have to deal with are scientists, quite a few will be hard to convince that vigorous physical exercise is of benefit for their professional activity, so it should be easier to realise my recommendations with respect to preflight athletic training.

G.Perdriel: Ne pensez-vous pas qu'un entraînement type "endurance" ne puisse être profitable dans l'entraînement des astronautes?

K.E.Klein: I do not quite understand what you mean by "resistance", we do not utilise this expression in the German Air Force. I have the idea you are talking about interval training. Is that correct? Well, if you are talking about the benefit of having a higher heart cavity, I do not think you can create or produce a higher heart cavity without producing at the same time those morphological changes which we do not want. So, I do not think we can make a departure between what you call resistance training and what we call athletic endurance training.

PSYCHOMETRIC CHARACTERISTICS OF ASTRONAUTS

Bryce O. Hartman
Richard C. McNee
USAF School of Aerospace Medicine
Brooks Air Force Base, Texas, 78235

SUMMARY

Detailed information on the role of psychological testing in the selection process for NASA astronauts has been reported only in a fragmentary manner because of the sensitive nature of this information. With the lapse of time since the initiation of the U.S. manned space program, this information has become essentially of only historic interest. However, because of the current activity in the European space agency, where there is a requirement for astronaut selection, psychometric procedures and data are of renewed scientific interest. An overview of the psychometric process and extensive statistical analyses are reported.

INTRODUCTION

The general procedures used in the selection process for National Aeronautics and Space Administration (NASA) astronauts have been reported in a variety of public and scientific media in the United States. Detailed information on psychological testing (one small part of the selection process) has been reported only in a fragmentary (and sometimes obscure) manner (3-6) because of the sensitive nature of such information.[1] Because of the lapse of time since the initiation of the U.S. manned space program (Mercury, Gemini, Apollo), this information has become essentially of only historical interest. However, the current activity in the European space agency, where there is a requirement for astronaut selection, renews scientific interest in psychometric procedures and data. This review will describe the psychometric process and present representative data.

OVERVIEW OF THE PSYCHOMETRIC PROCESS

Without exception, psychological testing has been embedded in a larger medical evaluation program. However, the overall medical program differed for Mercury versus remaining astronaut selection programs. Table 1 summarizes the two approaches. For the most part, candidates were examined in groups of six over a one-week period. Note the two-phase/two-location process for Mercury candidates, followed by consolidation of both the evaluation components and the location for subsequent groups of candidates. The findings in all cases were submitted to NASA in the form of an extensive consultation report on each candidate. NASA physicians were frequently present as advisors/observers during the medical evaluations. At such times, they participated actively in the case conferences held on each candidate.

The psychological tests administered to Mercury candidates at the Aerospace Medical Research Laboratory and to all subsequent candidates at the USAF School of Aerospace Medicine (USAFSAM) are shown in Table 2. In general, each laboratory used a conventional clinical psychological battery augmented because of special factors.

Data to be reported here will be limited to data available in reference 9 (Wilson), data from the first group of Gemini/Apollo candidates, and data from a subset of operational pilots among 250 control subjects examined at USAFSAM to develop a baseline for astronaut data. In all, over 350 candidates were tested psychologically, but some were candidates for special USAF programs. Much of these data will not be reported anywhere. With regard to the data sets reported here, not all psychological tests were administered to all candidate/control groups, an event not uncommon when a program extends across 3+ years and is directed at different times by different psychologists. At USAFSAM, the psychology team leaders were Hagen (Powell), Hartman, and Jennings, in that order. While this will constrain the findings reported here, there are enough data sets to yield an accurate picture of astronaut candidates and to reach conclusions on the contributions of psychometric data to the medical evaluation of NASA candidates.

STATISTICAL ANALYSES

Two kinds of statistical analyses (univariate and multivariate) were performed on three sets of data (Mercury, Gemini/Apollo, control) with a variety of subset combinations.

Univariate Analyses

Five groups of subjects were compared: the 7 selected and 24 not selected Mercury astronaut candidates, the 9 selected and 23 not selected Apollo astronaut candidates, and 50 pilots considered as a control group. Thirty-six psychological measurements were considered. The Mercury

---

[1] This review has been cleared by NASA Headquarters and by Headquarters USAF. In addition, a review relative to Privacy Act requirements was performed by ABG/JA, Brooks AFB, Tex.

TABLE 1. OVERVIEW OF PSYCHOMETRICS*

Procedures	Remarks
	Mercury Candidates
Medical evaluation	Performed at Lovelace Foundation, Albuquerque, New Mexico
Stress tolerance evaluation (ref. 9)[a]	Performed at 6570 AMRL, Wright-Patterson AFB, Ohio.
Battery of stress tolerance tests	Derivative of earlier drug studies using stress-provocative tests.
Psychiatric examination	Keyed to space flight stress.
* Psychometric testing	Conventional test battery.
* Pilot aptitude test battery	WWII pilot selection tests.
Psychiatric observation/brief psychometric tests; before and after each stress test.	Special brief tests from Moran battery.
	Gemini-Apollo Candidates
Medical evaluation (ref. 7)[b]	Performed at USAFSAM, Brooks AFB, Texas.
Stress tolerance evaluation	Reduced and revised to become provocative procedures of clinical medicine significance.
Psychiatric evaluation[c]	Integral part of medical evaluation.
* Psychometric evaluation	An integral support element of the psychiatric evaluation.

[a]Description of procedures and summary of findings.

[b]Description of procedures and summary of findings on the first 36 candidates examined at USAFSAM. Lawrence E. Lamb, M.D., former Chief, Clinical Sciences Division, USAFSAM, formulated and directed the evaluation program. The entire spectrum of USAFSAM medical departments participated on an equal basis.

[c]The psychiatric examination focused on four aspects: (a) the stress of space flight; (b) the demands of astronaut training; (c) the astronaut duties in addition to space flight, which were basically those of a project engineer for various spacecraft subsystems; and (d) the astronaut as a member/leader of an engineering/flight team.

candidates had data on only 16 of the measures and the controls had data on only 30 of the measures. Also, on 15 measures from the Edwards Personal Preference Schedule, data were available on only 26 of the control pilots. Percentile scores were used on the Edwards measures. The means are given in Table 3 and the standard deviations are given in Table 4 for the five groups.

Separate comparisons were made between the selected and not selected groups for the Mercury and the Apollo candidates. The only difference in means detected at the .05 level of significance was for Rating[2] for the Mercury candidates ($P < .005$). Variances differed at the .01 level for four of the measures, affecting the type of testing performed on the means. The differences in variances detected were for Rorschach F % for the Mercury candidates, and for Rorschach P and M and Edwards Deference for the Apollo candidates.

Separate comparisons were also made between the Mercury and Apollo candidates for the selected and not selected groups for the 16 variables with available data on both sets. The two sets differed significantly for two of the variables for both the selected and not selected groups--Rating and % Response to Chromatic Cards ($P < .001$). Also, the sets differed for Rorschach F % for the selected group and for Rorschach P and W for the not selected groups ($P < .005$). None of the tests of variances were significant at the .01 level.

A closer look at the detected heterogeneities of the variances in the pair-wise testing between selected and not selected groups for the two candidate sets shows an inconsistency between sets for one of the variables (Rorschach P). Another difference was on a variable not recorded on the Mercury candidates (Edwards Deference). For this variable, looking at the two variances relative to the control set variance, it appears that the not selected group variance estimate is low. For F % and

TABLE 2. PSYCHOLOGICAL TESTS ADMINISTERED

Mercury Candidates	Gemini/Apollo Candidates
1. Wechsler Adult Intelligence Scale	1. Wechsler Adult Intelligence Scale
2. Rorschach	2. Rorschach
3. Thematic Apperception Test	3. Thematic Apperception Test
4. Edwards Personal Preference Schedule	4. Edwards Personal Preference Schedule
5. Gordon Personal Profile	5. Gordon Personal Profile
6. Spatial Orientation; Space Memory; Gottschaldt Hidden Figures	6. Bender Visual-Motor Gestall Test
7. Draw-A-Person Test (Added by AMRL Project Officer)	7. Draw-A-Person Test (Requested by NASA)
8. Miller Analogies Test	8. Miller Analogies Test
9. Doppelt Math Reasoning Test	9. Doppelt Math Reasoning Test
10. Minnesota Engineering Analogies Test; Mechanical Comprehension	10. Minnesota Engineering Analogies Test
11. Minnesota Multiphasic Personality Inventory	11. Minnesota Multiphasic Personality Inventory
12. Raven Progressive Metrics; G-Z Spatial Visualization	(Note: Two psychomotor tests were added to the scientist-astronaut battery. One was reported in reference 7; the other was the Multidimensional Pursuit Test, which was required of the scientist candidates to predict success in pilot training.)
13. AFOQT; AQT (USN); Officer Effectiveness Inventory	
14. Sentence Completion Test; Shipley Personal Inventory; Outer-Inner Preferences; Pensacola "Z" Test; "Who Am I?" Test	
15. Extensive battery of pilot aptitude tests (WWII)	

M there was some consistency between the two candidate sets. The selected group had a smaller variance for F % ($P = .011$ for the Apollo set) and a larger variance for M.

Since Rating was the only variable with a detected mean difference between selected and not selected groups (only for Mercury), and Rating was not obtained for the controls, we decided to compare the control set with each of the two candidate sets ignoring selection grouping. The means and standard deviations for these three sets of data are given in Table 5.

The controls were significantly different from the other two sets in 5 of the 14 variables with data on all three sets. The controls were lower than the other sets for all three WAIS scores and for Rorschach F + % ($P < .001$) and higher for Rorschach ΣC ($P < .025$). Heterogeneities of variances detected in the comparison of the control set with the two candidate sets were for Rorschach W with the Apollo set and for Rorschach m with the Mercury set.

Of the 16 variables with data on only the Apollo and control sets four showed significant differences. The controls were higher on the three Edwards measures: Intraception ($P < .025$), Abasement ($P < .001$), and Nurturance ($P < .05$) and lower on the Miller Analogies Test ($P < .001$). None of the variances were heterogeneous at the .01 level of significance.

Interpretation of Univariate Analyses

On selected versus not selected, only the "rating" was significant. Selection was made by NASA, based on many more factors than psychometric data. Obviously, the psychology team leader was sensing not only test scores but also test and interview behavior in arriving at a rating. In the data, the significant differences for % Response to Chrom Cards can be considered a second-level

indicator of interview/test behavior. This awareness of test behavior supplementing test performance is inherent in all good clinical practice. It can be assumed that the NASA selection board responded to some of the same behavior influencing the psychologists back in the consultation arena.

TABLE 3. MEANS

	Variable	Mercury Selected	Mercury Not Selected	Apollo Selected	Apollo Not Selected	Control
1.	Clin. Psych. Rating	7.6	6.5	4.3	3.8	-
2.	WAIS FSIQ	135.1	131.8	134.9	131.0	118.6
3.	WAIS VIQ	136.0	131.2	133.4	129.4	118.9
4.	WAIS PIQ	129.9	128.6	132.4	129.3	115.8
5.	Ror. # Response	32.0	31.0	37.3	26.0	35.5
6.	Ror. F + %	90.0	86.5	87.7	90.1	72.8
7.	Ror. F %	39.0	37.5	51.6	45.1	44.8
8.	Ror. A %	31.7	36.5	42.6	42.3	39.6
9.	Ror. # Popular	4.3	5.3	7.4	7.1	6.2
10.	Ror. # M	2.9	3.2	4.6	2.7	2.5
11.	Ror. # W	16.1	14.7	11.7	9.4	12.0
12.	Ror. Σ C	3.6	3.1	4.0	2.7	4.6
13.	Ror. # m	1.6	1.4	2.8	1.6	1.5
14.	Ror. # FM	4.0	4.8	5.3	4.0	3.6
15.	Ror. # Shading Response	3.9	2.5	5.4	4.0	4.3
16.	Ror. % Resp. to Chrom Cards	36.1	35.0	58.6	54.0	-
17.	Ror. WIM	-	-	5.4	5.7	-
18.	Ror. M:FM + m	-	-	5.1	5.3	-
19.	Ror. FC:CF + C	-	-	4.7	4.4	-
20.	Ror. H + A:Hd + Ad	-	-	5.2	5.9	-
21.	Edwards Deference	-	-	49.7	50.6	49.2
22.	Edwards Order	-	-	49.3	49.2	51.0
23.	Edwards Exhibition	-	-	52.8	50.0	48.3
24.	Edwards Autonomy	-	-	51.0	52.0	49.6
25.	Edwards Affiliation	-	-	53.4	51.0	50.7
26.	Edwards Intraception	-	-	54.9	47.7	55.3
27.	Edwards Succorance	-	-	44.6	57.1	50.0
28.	Edwards Dominance	-	-	52.1	51.8	49.3
29.	Edwards Abasement	-	-	46.0	49.7	56.9
30.	Edwards Nurturance	-	-	49.4	47.1	52.7
31.	Edwards Change	-	-	51.4	50.2	49.5
32.	Edwards Endurance	-	-	53.7	50.2	52.2
33.	Edwards Heterosexuality	-	-	42.7	45.1	40.6
34.	Edwards Aggression	-	-	48.6	53.3	49.7
35.	Edwards Consistency	-	-	51.4	52.9	48.4
36.	Miller Anal Raw Score	-	-	63.2	61.1	44.0

On candidates versus controls, the expected results were obtained. The controls were not as high in intellectual resources, were more dependent, and more heterogeneous in test performance (see Table 5). The senior author would add (based on personnally adminstering around 100 of the Rorschachs out of the 350+ in the total group of special evaluations) that "special" candidates have a unique ability to deal with complex stimuli (e.g., a Rorschach card) in a simultaneously matter-of-fact and creative, emotive way--the latter without any disturbance in psychic equilibrium. This trait of astronaut candidates is distinctly different from the performance on psychological tests of the typical psychiatric patient seen on the consultation service at USAFSAM.

In general, the differences are small, scattered, and not very striking. The candidates are a brighter, better psychologically integrated, more independent, and a more homogenous group than a randomly selected subset of USAF control group subjects. In addition, the successive group of Gemini/Apollo candidates were highly similar, undoubtedly because each subgroup met the same initial screening standards.

Multivariate Analyses

Using a multivariate approach, comparison was made of the selected and not selected groups of the Apollo candidates. A stepwise procedure was used to obtain the subset of variables to analyze, considering only the 14 variables available on all three sets of data, so that further comparisons could be made if desired. With the stepwise procedure, each variable was in turn forced in as the first variable; the best discriminating variable in combination with the first variable was added as the second variable, providing it would improve discrimination at the .05 level of significance. Additional variables would be added in a similar manner, until no remaining variable would significantly improve discrimination.

of blood in the lower extremities: It compresses veins and pumps blood toward the heart, thus improving venous return and enlarging stroke volume. The more this action can be

TABLE 4. STANDARD DEVIATIONS

	Variable	Mercury		Apollo		
		Selected	Not Selected	Selected	Not Selected	Control
1.	Clin. Psych. Rating	0.60	0.88	1.52	0.79	-
2.	WAIS FSIQ	3.7	6.8	6.8	6.3	7.1
3.	WAIS VIQ	4.3	7.3	6.2	5.4	8.6
4.	WAIS PIQ	4.8	7.7	7.9	10.9	8.0
5.	Ror. # Response	15.6	18.2	15.5	13.8	27.8
6.	Ror. F + %	8.8	8.3	11.5	9.4	19.8
7.	Ror. F %	4.9	17.4	7.7	18.7	17.6
8.	Ror. A %	12.7	9.6	11.7	10.6	12.0
9.	Ror. # Popular	1.8	2.2	3.6	1.7	2.9
10.	Ror. # M	3.2	1.9	3.2	1.6	2.7
11.	Ror. # W	6.8	6.7	6.0	3.9	8.0
12.	Ror. Σ C	1.9	1.9	1.8	2.0	3.4
13.	Ror. # m	1.3	1.3	1.8	1.7	2.1
14.	Ror. # FM	2.4	3.3	2.7	2.3	2.8
15.	Ror. # Shading Response	2.9	2.5	2.8	2.8	4.5
16.	Ror. % Resp to Chrom Cards	8.0	7.8	7.0	7.9	-
17.	Ror. W:M	-	-	1.7	1.5	-
18.	Ror. M:FM + m	-	-	1.7	1.6	-
19.	Ror. FC:CF + C	-	-	2.1	2.5	-
20.	Ror. H + A:Hd + Ad	-	-	1.8	2.5	-
21.	Edwards Deference	-	-	11.4	5.6	8.5
22.	Edwards Order	-	-	9.7	12.2	10.4
23.	Edwards Exhibition	-	-	6.4	10.5	10.3
24.	Edwards Autonomy	-	-	9.5	10.2	8.3
25.	Edwards Affiliation	-	-	6.0	9.7	11.6
26.	Edwards Intraception	-	-	6.1	10.5	7.3
27.	Edwards Succorance	-	-	5.5	10.9	9.8
28.	Edwards Dominance	-	-	11.2	8.8	7.5
29.	Edwqrds Abasement	-	-	6.3	6.9	10.0
30.	Edwards Nurturance	-	-	9.3	6.7	9.9
31.	Edwards Change	-	-	7.3	8.6	8.4
32.	Edwards Endurance	-	-	10.3	10.6	11.0
33.	Edwards Heterosexuality	-	-	7.2	11.8	13.5
34.	Edwards Aggression	-	-	6.9	7.8	8.9
35.	Dewards Consistency	-	-	8.9	9.6	13.0
36.	Miller Anal Raw Score	-	-	8.1	10.5	13.4

The best set of variables found by this technique was VIQ and R. There was a significant difference between groups (P = .026) using these two variables. Using the best discriminating linear combination of VIQ and R resulted in misclassification of 5 of the 9 selected and 1 of the 23 not selected Apollo candidates. Therefore, about a 19% error rate in classification in this set of data. One would expect an even higher error rate in using the criteron determined from this set to classify another set of data.

As the final step in statistical analysis, the 14 variables available on all three sets of data were factor analyzed using the Minres method which minimizes the squares of the residuals (ignoring the diagonal elements). These factors were then rotated to "simple structure" using the Quartimax method. The Minres method of factoring--when rotated to canonical form--leads to the Principal Axis factors, if the communalities obtained by the Minres method are used on the diagonal of the correlation matrix. The communality estimates are obtained as a part of the solution.

The use of all 14 variables leads to near-singularities of the correlation matrices, so we deleted FSIQ (the main cause of the near-singularities) and P from the set of variables. Using the remaining 12 variables, three factors were extracted and rotated. The three factors showed many inconsistencies between the three sets of data. Since the control subjects were deemed to be psychologically different from the more selective astronaut candidates, we looked at the factor loadings for just the two sets of astronaut candidates. Table 6 gives the factor loadings, omitting the loadings when both sets had a loading less than .3. The communality estimates are also given in Table 6.

To help interpret the three factors, the tests were categorized into four groupings for each factor, determined by the levels of the two loadings. These groupings are given in Table 7 for each of the three factors. Due to the definitions of the categories, it is possible for some of the tests in the inconsistent category to have loadings that are not too different. Probably the variable "least inconsistent" is shading for factor 3 (loadings of -.23). One of the most striking inconsistencies is PIQ for factor 3. Here, the signs are reversed and both loadings are relatively high. Changing the signs on one set of loadings would eliminate this inconsistency, but cause other tests to be inconsistent.

TABLE 5. DATA COMBINED FOR SELECTED/NOT SELECTED

	Variable	Means			Std. Dev.		
		Mercury	Apollo	Control	Mercury	Apollo	Control
1.	Clin. Psych. Rating	6.7	3.9	-	0.94	1.05	-
2.	WAIS FSIQ	132.5	132.1	118.6	6.3	6.6	7.1
3.	WAIS VIQ	132.3	130.5	118.9	7.0	5.8	8.6
4.	WAIS PIQ	128.9	130.2	115.8	7.1	10.1	8.0
5.	Ror. # Response	31.2	29.2	35.5	17.4	15.0	27.8
6.	Ror. F + %	87.3	89.4	72.8	8.4	9.9	19.8
7.	Ror. F %	37.8	46.9	44.8	15.4	16.5	17.6
8.	Ror. A %	35.4	42.4	39.6	10.3	10.7	12.0
9.	Ror. # Popular	5.1	7.2	6.3	2.1	2.3	2.9
10.	Ror. # M	3.1	3.2	2.5	2.2	2.3	2.7
11.	For. # W	15.0	10.0	12.0	6.6	4.6	8.0
12.	Ror. Σ C	3.2	3.1	4.6	1.9	2.0	3.4
13.	Ror. # m	1.4	1.9	1.5	1.3	1.8	2.1
14.	Ror. # FM	4.6	4.3	3.6	3.1	2.5	2.8
15.	Ror. # Shading Response	2.8	4.4	4.3	2.6	2.9	4.5
16.	Ror. % Resp. to Chrom. Cards	35.2	55.3	-	7.7	7.8	-
17.	Ror. W:M	-	5.8	-	-	1.5	-
18.	Ror. M:FM + m	-	5.2	-	-	1.6	-
19.	Ror. FC:CF + C	-	4.5	-	-	2.3	-
20.	Ror. H + A:Hd + Ad	-	5.7	-	-	2.3	-
21.	Edwards Deference	-	50.3	49.2	-	7.5	8.5
22.	Edwards Order	-	49.2	51.0	-	11.4	10.4
23.	Edwards Exhibition	-	50.8	48.3	-	9.5	10.3
24.	Edwards Autonomy	-	51.7	49.6	-	9.9	8.3
25.	Edwards Affiliation	-	51.7	50.7	-	8.8	11.6
26.	Edwards Intraception	-	49.7	55.3	-	10.0	7.3
27.	Edwards Succorance	-	46.4	50.0	-	9.7	9.8
28.	Edwards Dominance	-	51.9	49.3	-	9.3	7.5
29.	Edwards Abasement	-	48.7	56.9	-	6.8	10.0
30.	Edwards Nurturance	-	47.8	52.7	-	7.4	9.9
31.	Edwards Change	-	50.6	49.5	-	8.2	8.4
32.	Edwards Endurance	-	51.2	52.2	-	10.5	11.0
33.	Edwards Heterosexuality	-	44.4	40.6	-	10.7	13.5
34.	Edwards Aggression	-	51.9	49.7	-	7.8	8.9
35.	Edwards Consistency	-	52.5	48.4	-	9.3	13.0
36.	Miller Anal Raw Score	-	61.7	44.0	-	9.8	13.4

TABLE 6. FACTOR LOADINGS AND COMMUNALITIES
FOR MERCURY (M) AND APOLLO (A) DATA

Test	Factor 1		Factor 2		Factor 3		Communalities	
	M	A	M	A	M	A	M	A
VIQ	.43	-.00			-.18	.34	.23	.12
PIQ	.37	.07			-.44	.63	.40	.41
R	.93	1.00					.96	1.00
F + %			-.58	.18	.06	-.45	.34	.24
F %	.39	.12	-.29	-.58			.30	.36
A %	.37	-.07	-.05	-.49			.19	.25
M	.35	.47			.42	.47	.30	.45
W	.32	.32	.85	.41			.84	.32
ΣC	.17	.35	.77	.63			.64	.52
m	.29	.58					.12	.46
FM	.84	.66			.26	.37	.79	.58
Shading	.37	.66	.56	.37	-.32	-.23	.55	.63

Interpretation of the Multivariate Analyses

In the initial multivariate analysis, the best combination of variables was Verbal IQ from the Wechsler Adult Intelligence Scale and number of responses (R) from the Rorschach. This finding is completely consistent with an early (circa 1963) unpublished factor analysis of Mercury data, performed to provide a conceptual framework to better understand the test behavior of subsequent candidates. Our interpretation then and now is that those candidates who feel free to "produce" psychologically in response to test material make a better impression on the examiner. We should add that the "productions" must be integrated and within normal bounds to maintain the examiner's favorable impression.

TABLE 7. GROUPING OF TESTS INTO FOUR CATEGORIES FOR EACH FACTOR

Category						
	Factor 1					
Major[a]	R	FM				
Moderate[b]	M	W	M	Shading		
Negligible[c]	F + %					
Inconsistent[d]	VIQ	PIQ	F %	A %	ΣC	
	Factor 2					
Major	ΣC					
Moderate	F %	Shading				
Negligible	VIQ	PIQ	R	M	m	FM
Inconsistent	F + %	A %	W			
	Factor 3					
Major						
Moderate	M	FM				
Negligible	R	F %	A %	W	ΣC	m
Inconsistent	VIQ	PIQ	F + %	Shading		

[a]Both loadings $\geq .5$
[b]One loading $>$ .35 and other loading $\geq$ .20 with difference $\leq$ .40 or both loadings $\geq$ .30 with difference $\leq$ .40
[c]Both loadings $<$ .3
[d]Not one of above

In the subsequent multivariate analysis (factor analysis), we obtained findings supporting the initial analysis. Major loadings on factor 1 are R (number of responses on the Rorschach), which demonstrates willingness to "Produce," and FM (movement responses on the Rorschach) which reflects ability to keep the content during high productivity within normal bounds. Moderate loadings on M (human movement responses) and W (whole inkblot responses) demonstrate the tempering of productivity by the high intellectual resources of the candidates. The major loading in factor 2 is ΣC (sum of color responses) demonstrating integrated responsiveness to one emotive aspect of Rorschach stimulation. Moderate loadings on F % (controlled conventional responses to the form of the inkblot components) coupled with shading (responses to shading variations perceived in the inkblots) which is the second emotive component of the Rorschach stimuli. Therefore, factor 2 indicates that the productivity identified in factor 1 is tempered by a combination of controlled sensitivity and responsiveness in conventional ways. Factor 3 adds nothing to this interpretation.

In summary, the multivariate analyses demonstrate the candidate's *willingness* to "produce" in response to test material, coupled with the added ability to respond both sensitively and creatively or in a conventional matter-of-fact manner, as appropriate to the stimulus material.

Brief note should be taken of the inconsistency of PIQ (Wechsler Adult Intelligence Scale Performance IQ) in factor 3 of the factor analysis. The senior author was struck by the occasional unexpected deviation in PIQ performance among the NASA candidates, when viewed in relation to all other test scores for those candidates. We are unable to explain this deviation; we have hypothesized that the creativity/sensitivity components of the astronaut personality structure result in unexpected "blocks" in the performance of the candidates at unpredicatable points on some PIQ subtests. We are unable to defend this hypothesis with supportive data or observations beyond what we have stated here.

SUMMARY AND CONCLUSIONS

The extensive statistical analyses reported here were a necessary prerequisite to reaching the significant points of this paper. Given a certain degree of editorial leeway, our conclusions are as follows:

a. The psychometric process, embedded in a medical evaluation environment, seems to function comfortably.

b. The psychometric process yields data which, when viewed outside the context of the medical evaluation environment, are of largely unimpressive value in identifying the "best" candidates from among a superior group. In fact, psychometric data used indiscriminately outside the appropriate context would, in our opinion, be disastrous.

c. As an information base for a more inclusive psychiatric-psychologic assessment the psychometric process is generally useful/desirable and occasionally provides critical insights.

d. The brief verbal psychometric description of an astronaut is:

He is brighter than most.

He is better integrated than most.

He is more independent than most.

He has a good balance between sensitivity/creativity and conventionality. (See references 1 and 2 for elaborations on this point.)

e. The brief data description to amplify the verbal psychometric description above can be extracted by the interested reader from Tables 3, 4, and 5.

f. None of the above will be of any particular surprise to the practicing clinical psychiatrist or psychologist.

REFERENCES

1. Fine, P., and C. F. Jennings. Personality development; Applications of theory to problems of aerospace selection. Aerosp Med 37:695-701 (1966).

2. Fine. P., and B. O. Hartman. Psychiatric strengths and weaknesses of typical Air Force pilots. SAM-TR-68-121, Nov 1968.

3. Flinn, D. E., et al. Psychiatric and psychologic evaluation. In L. E. Lamb (ed.). Aeromedical evaluation for space pilots. SAM Special Report, USAF School of Aerospace Medicine, Brooks AFB, TX, July 1963.

4. Flinn, D. E. Psychiatric factors in astronaut selection, pp. 87-95. In F. E. Flaherty (ed.). Psychophysiological aspects of space flight. New York: Columbia University Press, 1961.

5. Jennings, C. F. Psychologic test profiles of special groups. Proceedings of the Fourth Annual Conference of Air Force Clinical Psychologists, USAF School of Aerospace Medicine, Brooks AFB, TX, Dec 1963.

6. Jennings, C. F. Use of normative data in the psychological evaluation of flying personnel, pp. 37-51. In C. J. B. Perry (ed.). Psychiatry in aerospace medicine, Vol. 4, No. 1, Winter 1967.

7. Lamb, L. E. Aeromedical evaluation for space pilots. SAM Special Report, USAF School of Aerospace Medicine, Brooks AFB, TX, July 1963.

8. McKenzie, R. E. A systems task used in the stress testing of special mission personnel. Human Factors, 1:585-590 (1959).

9. Wilson, C. L. (ed.). Project Mercury candidate evaluation program, WADC-TR-59-505, Wright Air Development Center, Wright-Patterson AFB, Ohio, Dec 1959.

DISCUSSION

J.Salvagniac: A-t-on observé des troubles psychiques ou des anomalies du comportement chez les astronautes dans les jours ou les semaines qui on suivi leur retour sur terre?

B.O.Hartman: I have no answer for that question. I have no data on it. My goal in the astronaut program was limited simply to the medical evaluation which preceded selection.

A.N.Nicholson: Do you consider that psychometrics have a contribution to make in the selection of future astronauts?

B.O.Hartman: Yes, provided psychometrics are considered in the appropriate context. First, psychological tests should be part of the medical evaluation, not separate. Second, it should be remembered that the tests are better at identifying the less well qualified candidates, and poorer at identifying the most qualified candidates.

A.N.Nicholson: In the original evaluation you carried out, was special attention paid on the attitude of the candidates toward their family life at home? Do they have a special relationship to their wife and children, that other candidates don't have?

B.O.Hartman: They did not have a special relationship. Their attitude toward their wives was like the attitude of the typical Air Force pilot toward his wife.

PSYCHOLOGICAL SELECTION OF ASTRONAUT-SCIENTISTS (PAYLOAD SPECIALISTS)

by

Klaus-Martin Goeters, Dipl.-Psych.
Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt
Institut für Flugmedizin
Luftwerft / Weg beim Jäger
2000 Hamburg 63
FRG

SUMMARY

There are two important differences between the early astronauts (e.g. of Apollo) and the astronaut-scientists of future Spacelab missions: a. All astronauts up to now had relevant experiences before becoming astronauts. They were active aircraft pilots. So they were familiar with handling complicated technical systems, work under time pressure and cooperate in teams. Astronaut-scientists will come out of the laboratory routine of research institutes where work requirements usually are contrary to the demands of air or spacecraft operation. b. The space-oriented training of astronaut-scientists will be short. Both facts imply that with unselected scientists the probability of failures during space flights may be relatively high. Therefore, psychological testing of Spacelab-payload specialists is mandatory. Generally, astronaut-scientists should have these characteristics: 1. High basic technical comprehension and practical skills. 2. High motivation. 3. Adequate group behavior. 4. Emotional maturity and stress resistence. The significance of these psychological factors for working in confinement are demonstrated by experimental results.

Psychological aspects have always been considered as important factors in determining human performance in manned spacecrafts. One aspect is crew selection. Some more or less systematic work in this field has been done since the early sixties. At that time task analysis showed a high similarity between the work structure of jet pilots and of the astronaut pilots of Gemini, Mercury and Appollo. Thus, recruiting the astronauts from experienced cockpit personnel was recognized to be the best selection method. Psychological examinations were only confirming the high level of performance and the personal qualification of these applicants. FLINN et al. (1963) examining 32 space candidates found that their mean WAIS IQ was 132, which is in the highest category of this test. The EPPS personality profile for the same candidates was almost identical with the results of 100 operational flying officers, both groups being compared with a college population. It was observed that a standard astronaut candidate scored much higher on the achievement, dominance and endurance motives, as well as manifesting significantly greater needs for deference and change. At the same time this group tended to show less abasement and nurturance. The WAIS IQs as well as the personality scores for the astronaut applicants were falling in a relatively narrow range. This homogenity probably resulted from prior selection when entering the Air Force and also indicates the occupational adaptation. Because of the high homogenity, selection by the usual tests was not possible. Therefore considerable weight was given to the candidates' current situation (family problems, job satisfaction, use of alcohol, etc.) which seemed to be related to job performance and effectiveness.

Although spacecraft operation was their main task, astronaut pilots always had to conduct a diversity of scientific experiments. This part was growing over the years. It became evident that many experiments could be performed more effectively by scientists than by space pilots. In 1965 NASA consequently selected a group of scientists for astronaut training. But all of these scientists had still been licenced pilots. Those being accepted received a full training in spacecraft operation. Nevertheless taking scientists as astronauts was an important step. These scientists should contribute to a higher efficiency of space research by their academic knowledge accompanied by spontaneity and motivation. To allow the scientist some free experimentation, it was decided, that a program for an orbit flight should not be too strict.

Skylab was the demonstration for the rightness of this attack.

The role of scientists participating in space flights was developed. So future Spacelab projects will show a clear division of the mission tasks:

A. Orbiter crew consisting of

commander
pilot
mission specialist

The orbiter crew will be responsible for a safe flight operation and for reaching the mission goals. The crew members are conventional astronaut pilots. Their selction does not raise any new questions, because they will be recruited as before from experienced jet pilots.

B. Payload crew consisting of

payload specialists (up to 4)

The payload specialists are scientists who are responsible for realizing the preplanned space experiments. If ever possible they will carry out work of their own discipline to guarantee an optimal solution of the research problems. As payload specialists are a new species of astronauts we have to think about their selection.

In principle, each scientist or engineer from the nations engaged in the Spacelab project can apply for a payload specialist's position. There will be a very heterogen population of applicants. Individual differences in this group will be stronger than in the highly preselected group of jet pilots representing up to now the reservoir of astronauts. Another point is that payload specialists will receive only a short space training. During this training low abilities and an inadequate group behavior will not be improved to a remarkable degree. So we can not rely on counteracting individual incapacity by forced training.

One may ask, whether an academic degree is a sufficient qualification to become a payload specialist. We have to doubt this, because the work an board Spacelab will be very different from the routine work in research institutes. So only a limited prediction of behavior seems to be possible by scientific qualification. To emphasize the importance of this matter an example from aviation is given: Experience of civil airlines where military pilots were trained to become line pilots is showing that only about 40 - 50 per cent can be accepted as civil pilots (e.g. TRANKELL). The reason for this phenomenon is that the work requirements are not overall identical, but differ in some aspects between military and airline service.

The hitherto undertaken space flights could only give a limited insight into behavior and performance problems, because there were only few subjects and generalizations are not justified. More systematic information originates from selection and supervision of aircrews and behavior studies in underwater habitats (e.g. the US Tektite II and the German UWL "Helgoland"). Generally, the following points should be given attention when selecting payload specialists:

1. High basic technical comprehension and practical skills
2. High motivation
3. Adequate group behavior
4. Emotional maturity and stress resistance

ad 1. A rough comparison between work requirements in Spacelab and the routine work in research institutes shows that during the space flight the experimental work will be highly packed. Theory will stand back during this phase and practical problems will be dominating.

Scientists usually have a high cognitive standard as measurements of intelligence always indicate (e.g. AMTHAUER, 1970). The prevailing engagement with theory is often accompanied by neglecting practical skills. At least scienfitic education does not mean, if ever, a strong selection by practical abilities and we expect considerable individual differences between scientists in their ability to manage practical problems. It was found, that even the astronaut applicants of the sixties were varying much more in the performance and attention tests than in the more verbal-oriented test scales, although this group had much practice in aviation (FLINN et al., 1963).

Only an optimal use of orbit time will justify the tremendous costs for Spacelab. Therefore, an important characteristic of work in Spacelab will be the time stress, which is necessary in order to realize a broad research program during the relatively short stay in orbit. It is assumed that time stress is the aspect in which work on board the Spacelab and the normal scientific routine on earth differ most widely.

Measuring the capacity for quick and correct handling of technical equipment is a crucial part of the psychological examination of pilot candidates. So we can apply test methods out of this field for the selection of payload specialists. Evaluation of the following aptitudes is suggested:

a. Basic knowledge in physics and technology;
b. Mathematical and logical reasoning;
c. Spatial orientation;
d. Concentration functions as perceptual speed, memory and numerical ability;
e. Motor functions: Finger and hand dexterity will be more important than the psychomotor coordination which is a critical factor in aircraft handling.

Tests measuring these aptitudes are described elsewhere (e.g. GUILFORD & LACEY, 1947; KIRSCH, 1976).

ad 2. It is well known in applied psychology that the performance of a person does not only depend on his abilities, but also on emotional, motivational and social factors. How these factors will influence work efficiency under confinement is demonstrated by studies in underwater habitats. In particular, the Tektite II project (see HELMREICH, 1971) gives relevant information concerning the problem under discussion. The behavior studies of this project were especially designed for scientists working in space capsules. A total of 40 scientists participated in this project. Most of them have been marine biologists and geologists. They were living in 5-person-groups (4 scientists plus 1 diver engineer) for 2 or 3 weeks to carry out marine experiments. They were observed around the clock by means of closed circuit television. The observers were trained students of psychology. They rated the aquanauts' behavior every 6 minutes according to some welldefined categories. The ratings were analyzed by statistical methods. Of main interest was the question, which factors influence work output most. So it should be investigated, which psychological methods could predict individual differences in working behavior best.

Given that over 35,000 observations were made per subject in this study it is hard to summarize all of the results. HELMREICH (1971, page VIII-59) stated this: "The first conclusion which can be drawn from the research conducted on human behavior in Tektite is that both male and female aquanauts can adapt successfully to life in a confined environment such as the habitat. Not only can individuals cope adequately with confinement and isolation, they can also perform work roles effectively in such a setting. The amount of work accomplished by the aquanauts was great - probably surpassing the average daily time expenditure of most scientists and engineers in normal, terrestrial environments. Within this overall excellent work output, there were, however, large team and individual differences, ...". The top 10 scientists on the work criterion averaged 8.5 hours a day working (all sleeping and leisure subtracted). On the contrary the aquanaut who worked least spent an average of 4.3 hours per day working.

Beside other test data a Life History Questionnaire (LHQ) proved to be a valid instrument in predicting individual differences in habitat behavior. Using the Wherry test selection method (WHERRY, 1946) variables were selected from the pool of LHQ data to predict aquanaut performance. The resultant multiple correlation was .69, accounting for 48% of the criterion variance. The variables used in this prediction were: financial independence, school performance, religious activity, work (during the school year) and work (during summer vacations). Especially the fact that the religious activity correlated negatively with the criterion shows obviously that underlying motivational and interest factors are the main sources for determining the correlations. Because this relationship is not specific, but rather general in nature we have to conclude that motivation will play an overwhelming role for the efficiency of payload specialists, too.

ad 3. Another result from Tektite II: "Correlations between the overall gregariousness of each aquanaut (time spent with other aquanauts in conversation) and total marine science and between time spent communicating with the topside command van and total marine science were computed for scientist-aquanauts. The correlation between gregariousness and total marine science was .59, showing clearly that interaction with peers is positively associated with productivity." (HELMREICH, 1971, page VIII-39). From this result it seems, that the aquanaut (or astronaut) should have a personal disposition, which guarantees an active cooperation with crew members. Therefore a desirable applicant is a man with medium-high extraversion, high personal warmth and low aggressiveness.

ad 4. Space flights are technical adventures into a hazardous environment. Many situations may be perceived as dangerous. Like aviators the astronaut should show high emotional stability and personal maturity to withstand and control feelings of anxiety.

From all the situational components of a space flight the confinement is often considered to be very stressful. But this is only true for the one man situation. As experiments show, anxiety reactions and perceptual aberrations can occur during a one man flight in a space cabin simulator very soon leading to an early end of a mission (FLAHERTY et al., 1960). But with two or more men in the space cabin this behavior was not observed (CRAMER & FLINN, 1963). The presence of another crew member is giving sufficient resistence toward the emotional effects of confinement. Emotional stresses in closed systems like a spacecraft or an underwater habitat do more often originate from malfunctions of the technical systems than from any other factor.

We have reviewed some important psychological factors which should be considered in the selection of astronaut scientists. But we did not mention any test measuring them. This is because we cannot apply the same psychological test system for the applicants from all the nations participating in the Spacelab project. There is a cultural dependency of psychological factors and their measurement (GOETERS, 1975). Especially, this is true for the personality traits. To give an example, the German translation of the well known 16-PF-Test (CATTELL, 1965) failed to be of value in the selection of pilot applicants for a civil aviation company in the FRG. So it was decided to develop a new multidimensional personality questionnaire. Test construction resulted in a diagnostic method of high reliability (KIRSCH et al, 1975). The questionnaire now has been used since years with confidence. In the international cooperation of Spacelab an obligatory catalogue of psychological requirements should be established. But the psychological examination of applicants must be done by national selection boards with culture and language adapted methods.

To realize an efficient psychological selection, care has to be taken that the number of applicants is high enough. It is known from airline pilot selection that only about 10 - 20 per cent of all applicants will pass the examination. If we take this as a guide line and also take into account irregularities of small samples it does not seem too extreme if one payload specialist is selected out of a group of twenty suitable scientists. Costs for this selection are very low compared with the tremendous financial loss of an unsuccessful mission in orbit.

REFERENCES:

1. AMTHAUER, R. — Intelligenz-Struktur-Test. Göttingen: Hogrefe, 1970.

2. CATTELL, R.B. — The scientific analysis of personality. London: Penguin Books, 1965.

3. CRAMER, E.H., FLINN, D.E. — Psychiatric aspects of the SAM two-man space cabin simulator. SAM Report - TDR - 63 - 27 (1963).

4. FLAHERTY, B.E. et al. — Psychiatry and space flight. SAM Report - TDR - 60 - 80 (1960).

5. FLINN, D.E. et al. — Psychiatric and psychological evaluation. In Lamb, L.E. (ed.): Aeromedical evaluation for space pilots. Brooks Air Force Base (Texas): USAF School of Aerospace Medicine, 1963.

6. GOETERS, K.M. — Psychodiagnostik im Dienst der Entwicklungshilfe: Die Auswahl von jemenitischen Bewerbern für die Flugzeugführerausbildung. Z. exp. angew. Psychol. 22 (1975).

7. GUILFORD, J.P. LACEY, J.I. — Printed classification tests. Washington: Defense Documentation Center, 1947.

8. HELMREICH, R. — The Tektite II human behavior program. In Miller, J. et al. (eds.): Tektite II: Scientists in the sea. Washington: Government Printing Office, 1971.

9. KIRSCH, H. — Die psychologische Auswahl von Bewerbern für die fliegerische Laufbahn. Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt IB 355 - 76 - 02 (1976).

10. KIRSCH, H. et al. — Faktorenanalyse eines neuen mehrdimensionalen Persönlichkeits-Fragebogens. Deutsche Luft- und Raumfahrt FB 75 - 20 (1975).

11. TRANKELL, A. — The SAS system of selection of pilots. (SAS internal paper)

12. WHERRY, R.J. — Test selection and suppressor variables. Psychometrika 11 (1946).

EXPERIMENTAL BASIS FOR THE USE OF HYPNOTICS BY AEROSPACE CREWS

by

Nicholson, A.N., Borland, R.G., Clarke, Coral H. & Stone, Barbara M.
Royal Air Force Institute of Aviation Medicine
Farnborough, Hampshire, United Kingdom

INTRODUCTION

Irregular rest and activity is an important aspect of aerospace operations, and skilled management of of work and rest cycles of flight crews is vital to the success of complex missions. Though space flight is not associated with gross changes in the sleep behaviour of man, sleep disturbance can be a problem. Adequate planning of work and rest cycles is essential, but hypnotics are useful in the management of crews, particularly during their adaptation to the new environment, and when space operations extend beyond several weeks.

We are interested in the effective use of hypnotics by flight crews. There are many problems associated with the use of hypnotics by persons involved in skilled activity, and, in the case of aerospace operations the problem is complicated by the need to sleep at unusual times of the day and night. This paper will review the work which has been carried out at the Royal Air Force Institute of Aviation Medicine on the immediate and residual effects of hypnotics on performance, the effectiveness of hypnotics, and the problems associated with the use of hypnotics at unusual times of the day.

Residual Effects on Performance

Many studies have investigated the effectiveness of hypnotics and the changes which they induce in sleep patterns, but less is known about their residual effects on performance. Von Felsinger, Lasagna & Beecher (1953) observed impaired performance on tests of visual perception, attention and computation up to 8h after pentobarbitone sodium (100 mg) and Kornetsky, Vates & Kessler (1959) reported deficits on digit symbol substitution and symbol copying around 14-15h after quinalbarbitone sodium (200 mg). More recently, behavioural impairments have been detected to 13h after amylobarbitone sodium (100 mg) (Malpas, Rowan, Joyce & Scott, 1970) and to 12h after butobarbitone sodium (100 mg) (Bond & Lader, 1972).

Tests which involve motor skill may be more sensitive than tests of cognition to the residual effects of a barbiturate (Bond & Lader, 1972). In this context McKensie & Elliott (1965) observed performance decrements on a visual pursuit tracking task 22h after secobarbitone sodium (200 mg), though no changes were detected after 100 mg of the drug (Hartmann & McKensie, 1966). The residual effects of hypnotics after their therapeutic purpose has been fulfilled need careful consideration, particularly if they are given to persons involved in skilled activity. We have studied this problem using the technique of adaptive tracking which demands a high level of skill acquired only by considerable practice.

METHODS

Measurement of Performance

Performance was measured using an adaptive tracking task. The task required the subject to position a spot inside a randomly moving circle displayed on an oscilloscope. The movement of the spot was controlled by a hand held stick. An error signal, proportional to the distance between the spot and the centre of the circle, controlled the difficulty of the task by modulating the mean amplitude of the movement of the circle. This technique provided the adaptive component of the task which maintained optimum performance of the operator.

The movement of the circle on the oscilloscope was produced by two independent maximum length binary sequences. Low pass filtering smoothed the output of the binary sequences and the movement of the circle was statistically random. Independent x and y signals derived from high grade potentiometers mounted on the control stick were fed via an 'aerodynamic loop' to the inputs of the oscilloscope. The loop avoided an artificial one to one relation between the control stick and spot movement and smoothed out any small steps caused by the potentiometer windings.

The oscilloscope (Airmec 383) had a distortion free medium persistence tube and displayed the task over an area of 20 x 20 cm. It was modified by the addition of x axis beam switching and allowed two independent signals to be displayed in each axis. A voltage proportional to the distance between the spot and the centre of the target circle was measured and the radial error signal computed. A voltage proportional to the square of the circle radius was subtracted from the square of the radial error signal. The output from the scoring circuit was fed to a voltage integrator and the output of the integrator, scaled from 0-10, controlled the mean amplitude of the task.

At the start of each experiment the output from the integrator was set at zero and the circle was stationary. The subject positioned the spot inside the circle and the negative error signal made the integrator output increase. The circle tended to move away from the spot and, when the spot could no longer be maintained inside the target circle due to the increasing difficulty of the task, the polarity of the voltage to the integrator reversed and the task became less demanding. The integrator had a long time constant which allowed each subject to 'warm up' gradually.

With zero error the task required about 25s to reach maximum difficulty. A constant displacement between the spot and the centre of the circle of 4 cm would reduce the task to zero difficulty within 6s. As the subjects became aware of the penalty of error signals they tried to avoid all errors, but the task did not permit a performance level of 10 to be reached.

An eight channel pen recorder monitored the equipment and the performance of each subject.

Experimental Procedure

Six healthy male subjects were used. Their ages ranged from 24-39 years (mean 32) and their weights ranged from 67-83 kg (mean 72). Instructions were given to all subjects to avoid alcohol and they were not involved in any other form of therapy. There were no restrictions on the consumption of non-alcoholic beverages. The experiments were carried out in a sound attenuated and air-conditioned room.

The subjects were required to reach a plateau level of performance on the task before studies commenced. In subjects familiar with this technique, such as pilots, this level of performance would be reached within about five days, but with laboratory personnel a plateau level of performance was usually reached with daily practice after 2-3 weeks. Training sessions were made available during the preceding week of each experiment to maintain levels of performance which had been reached during initial training.

Assessment of the effect of placebo or each drug was carried out over 2 days. On day 1, before the ingestion of placebo or drug, four assessments of performance were made at 0900, 1200, 1500 and 1800h. The capsule (placebo or drug) was given at 2300h the same evening and the subject slept at home. The subjects attended the laboratory on day 1 at 0830h, but were brought to the laboratory on day 2 between 0800h and 0830h. On day 2 performance was measured at the same time as on day 1 i.e. at 0900 (+10), 1200 (+13), 1500 (+16) and 1800h (+19h after ingestion of placebo or drug).

Experiments were separated by 4 weeks and each subject completed 4 experimental runs of 2 days. The capsules contained the placebo, heptabarbitone (200 mg, 300 mg or 400 mg), methaqualone hydrochloride (400 mg), nitrazepam (10 mg), flurazepam hydrochloride (30 mg) or pentobarbitone sodium (200 mg) given in a random order. The trial was double blind and placebo and drugs were presented in an identical form. On day 1 of each experiment the subjects were required to report to the laboratory at 0845h, but on day 2 of each experiment (after the overnight ingestion of placebo or drug) the subjects were collected from home at 0815h to avoid any oversleep.

Barbiturates

The studies on the residual effects of heptabarbitone demonstrated that performance decrements were related to dose, both in the persistence of the effects and in the decrement of performance at given time intervals. The normal therapeutic range for heptabarbitone as a hypnotic is 200-400 mg and decrements in performance were detected 10h after the ingestion of 200 mg. In this way the studies supported previous investigations carried out with other barbiturates (Von Felsinger et. al., 1953; Malpas et. al., 1970; Bond & Lader, 1972) but showed as did Kornetsky et. al. (1959) and McKensie & Elliott (1965), that impaired performance may persist much longer after higher doses which are still within the usually accepted therapeutic range. After heptabarbitone (400 mg) decrements in performance ($P = 0.01$) persisted to at least 19h after ingestion. (Fig. 1)

As well as the persistence of the effects of heptabarbitone the studies also showed that decrements in performance were dose related. Decrements in performance at the 10h interval were significant at the 5% level after 200 mg, at the 1% level after 400 mg. At the 13h interval no decrement in performance was observed after 200 mg, but impaired performance was detected after 300 mg ($P = 0.05$) and after 400 mg ($P = 0.001$) of the drug. The effect of 200 mg pentobarbitone sodium was similar to that of 400 mg heptabarbitone. (Fig. 2)

It is evident that the residual effects of barbiturates given overnight need careful attention. Previous studies using tests of visual perception, attention and computation (Von Felsinger et. al., 1953; Kornetsky et. al., 1959; Malpas et. al., 1970; Bond & Lader, 1972) and these studies using a task relevant to a particular skill showed that performance may be impaired after overnight ingestion of a barbiturate well into the next working day.

Benzodiazepines

The benzodiazepines led to consistent, though less severe, deficits in adaptive tracking. Impaired performance after nitrazepam persisted throughout the next day, but with flurazepam hydrochloride a rapid recovery of performance was observed after 16 hours. The residual effects of nitrazepam and flurazepam hydrochloride related to an occupation orientated task suggested that performance of complex skills was likely to be impaired thoughout most of the working day after maximum doses within the normal therapeutic range of each hypnotic. (Fig. 2)

4-quinazalone

The studies on the overnight ingestion of methaqualone hydrochloride (400 mg) revealed little, if any, residual effects on performance in man. Performance on adaptive tracking from 10h to 19h after ingestion was not impaired. The minimal residual effects of methaqualone hydrochloride are in contrast with those observed after barbiturates and benzodiazepines. With the overnight ingestion of heptabarbitone (400 mg) and pentobarbitone sodium (200 mg) decrements in performance on adaptive tracking persist to 19h, and with flurazepam hydrochloride (30 mg) and nitrazepam (10 mg), though decrements on adaptive tracking are not as severe as those observed after barbiturates, they persist to 16h and 19h respectively. (Fig. 2)

The studies suggested that methaqualone hydrochloride may prove to be a valuable hypnotic for occasional use by persons involved in skilled activity.

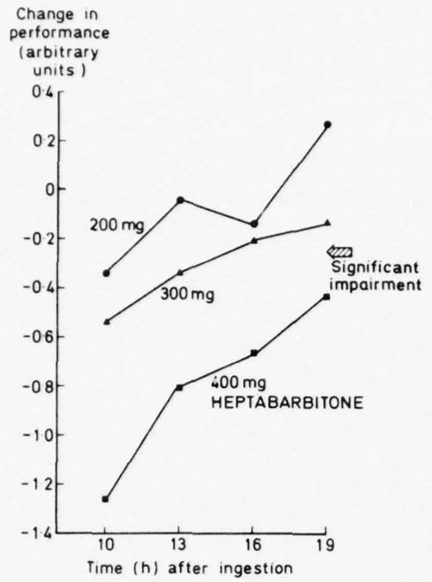


Fig. 1

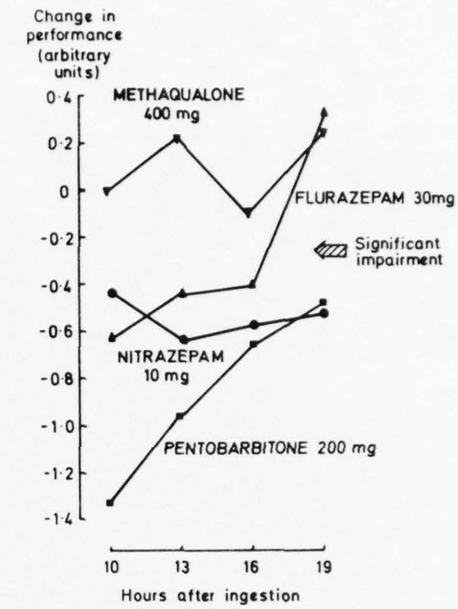


Fig. 2

		HOURS AFTER OVERNIGHT INGESTION			
		10	13	16	19
BARBITURATES					
Heptabarbitone	200 mg	*	NS	NS	NS
	300 mg	**	*	NS	NS
	400 mg	***	***	**	**
Pentobarbitone Na	200 mg	***	***	***	*
BENZODIAZEPINES					
Nitrazepam	10 mg	*	**	**	**
Flurazepam HCl	30 mg	**	*	*	NS
4-QUINAZALONE					
Methaqualone HCl	400 mg	NS	NS	NS	NS

*** = 0.1%;   ** = 1%:   * = 5%:   NS = Not Significant

Table 1

Summary of residual effects of drugs on visuo-motor co-ordination

Immediate Effects on Performance

In previous studies we examined the residual effects of hypnotics on human performance. The studies included observations on 1,4-benzodiazepines and it was shown that, as with many other hypnotics, impaired performance may persist well into the next day after overnight ingestion. Residual effects on performance may not be an essential property of an effective drug, and there are differences in the severity and persistence of performance decrements between hypnotics. Studies with methaqualone hydrochloride (400 mg) failed to reveal effects on performance from 10h after overnight ingestion, while with flurazepam hydrochloride (30 mg) recovery of function is delayed to the early part of the afternoon and with nitrazepam (10 mg) impaired performance persists to the early evening.

Drugs within a group, such as the benzodiazepines, may have different effects on performance as well as different therapeutic activity. In this context there is interest in benzodiazepines with the nitrogen atoms of the heterocyclic ring in the 1,5 position instead of the 1,4 position. An example is clobazam (Fig. 3) (1-phenyl-5-methyl-8-chloro-1,2,4,5-tetrahydro-2,3-dileto-3H-1,5-benzodiazepine, Hoechst Pharmaceuticals) which has been shown to be more active as a sedative in animals than chlordiazepoxide hydrochloride (Barzaghi, Fournex & Mantegazza, 1973), but which has been reported to have limited effects on human performance (Berry, Burtles, Grubb & Hoare, 1974). Both clobazam and chlordiazepoxide hydrochloride would appear to have a shorter duration of action than that of the 1,4-benzodiazepines used primarily as hypnotics, and so we have looked for immediate rather than residual effects. We have compared these drugs with diazepam (Fig. 3), which is known to lead to performance decrements in man (Jäättelä Männistö, Paatero & Tuomisto, 1971; Linnoila & Mattila, 1973). (Fig. 4)

The studies show that benzodiazepines with established therapeutic activity, such as diazepam and chlordiazepoxide hydrochloride, may have very different effects on performance. Diazepam (10 mg) leads to impairment on adaptive tracking for at least 2.5h after ingestion, whereas with chlordiazepoxide hydrochloride and clobazam, both ingested as a single 20 mg dose, there are no effects on adaptive tracking. However, with clobazam there was evidence of a trend of improved performance during the day. These findings suggest an effect of the drug, but it is considered that they provide little support for the observation that performance is impaired.

Though different drugs may have different effects on performance the rate of excretion will influence the persistence of impairment as well as the duration of therapeutic activity. Diazepam has pronounced initial effects on performance, but with a half life of between two and three hours (de Silva, Koechlin & Bader, 1966) there is a rapid recovery of function. In the present experiments the curves of recovery of function for reaction time and adaptive tracking respectively intersected the zero axes at 6h and 7.5h after ingestion. With chlordiazepoxide hydrochloride (10 mg) the initial effect on performance is limited, but it tends to persist, and this may be related to a half life which varies between 6 and 15.5h (Schwartz, Postma & Gaut, 1971). With this drug the curve of recovery for reaction time intersected the zero axis at 7.5h after ingestion. In a previous study a slow recovery in performance. greather than 19h, was observed after nitrazepam which has a long effective half life (Rieder, 1973). The short half life of diazepam with rapid recovery from impaired performance and the ability of subjects to assess their impaired performance accurately would suggest that diazepam may have a greater potential for use as an hypnotic than hitherto considered (Montagu, 1972).

The experiments emphasize the complexity of impaired performance after ingestion of drugs. It is evident that drugs, even within a broadly similar group, may have very different effects on performance. No definite effects on performance were observed after the 1,5-benzodiazepine, clobazam, but obvious performance deficits were observed after diazepam and chlordiazepoxide hydrochloride. On the other hand with the overnight ingestion of the 1,4-benzodiazepines, nitrazepam and flurazepam hydrochloride, residual effects on performance persisted well into the next day. Within the benzodiazepines the nature and persistence of impaired performance vary considerably and need careful consideration. It would appear that therapeutic activity and deleterious effects on performance can be dissociated, at least to some extent.

		HOURS AFTER MORNING INGESTION			
		0.5	2.5	5.5	9.5
1,4-BENZODIAZEPINES					
Diazepam	10 mg	***	**	NS	NS
Chlordiazepoxide HCl	20 mg	NS	NS	NS	NS
1,5-BENZODIAZEPINE					
Clobazam	20 mg	NS	NS	NS	NS

*** = 0.1%: ** = 1%: * = 5%: NS = Not Significant

Table 2

Immediate effects of benzodiazepines on visuo-motor co-ordination

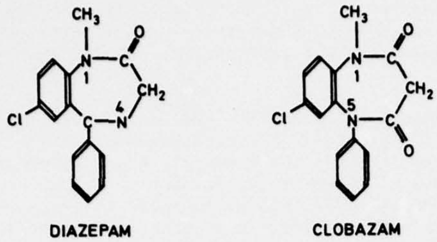
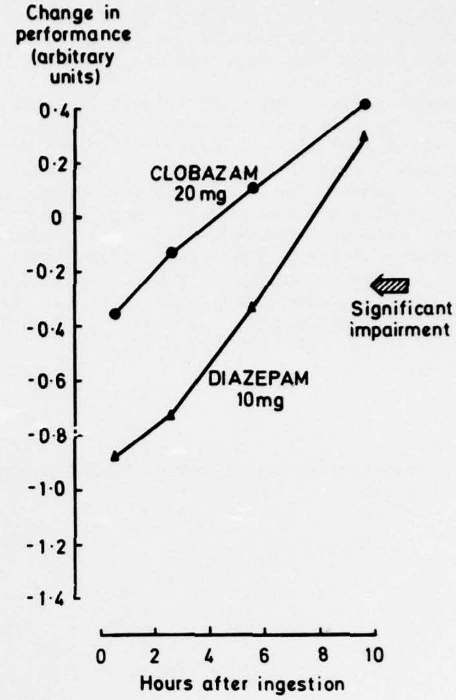


Fig. 3

Structural formulae of the 1,4-benzodiazepine, diazepam, and the 1,5-benzodiazepine, clobazam.



Immediate effects on visuo-motor co-ordination of diazepam (10 mg) and clobazam (20 mg).

Fig. 4

Studies on Sleep

In the previous studies we were concerned with the effect of hypnotics on performance using adaptive tracking as an occupation orientated task. With barbiturates and the 1,4-benzodiazepines, nitrazepam (10 mg) and flurazepam hydrochloride (30 mg), performance was impaired 16h or more after overnight ingestion, and these observations suggested that residual effects on performance may be an inevitable sequelae of an effective hypnotic. However, impaired performance does not persist beyond 10h with the overnight ingestion of methaqualone hydrochloride (400 mg), and that, with the morning ingestion of diazepam (10 mg), performance returns to control values within 7.5h. The restricted effects of diazepam on performance, together with its limited potential for misuse suggest that it could prove to be a useful hypnotic for persons involved in skilled activity.

Like many other benzodiazepines the behavioural activity of diazepam is related, not only to the pharmacokinetic and behavioural properties of the parent drug, but also to its metabolites, N-desmethyl-diazepam (nordiazepam) and 3-hydroxydiazepam (temazepam). In the present studies diazepam and these two primary metabolites were investigated.

METHODS

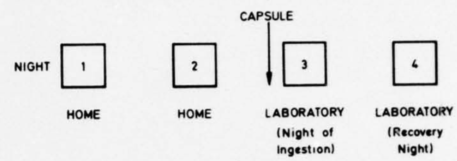
The subjects were six healthy male volunteers aged between 19 and 43 years. They were familiar with the laboratory, and with the techniques used in recording sleep activity. The assessment of the effect of each treatment (placebo or dose of a drug) involved 4 days. For 2 nights the subjects slept at home and retired at a set time between 2300 and 2330h, and for the next 2 nights the subjects slept in the sleep laboratory. They were required to refrain from napping and undue exercise, and to abstain from caffeine and alcohol after mid-day on the days which involved sleep recordings. The sleep laboratory was sound attenuated, and the temperature ($18 \pm 1^{o}C$) and humidity ($55 \pm 2\%$) were controlled. Nine to twelve days separated each assessment. The subjects reported at the sleep laboratory 1.5h before their set time to retire. At 0.5h before 'lights out' the subjects completed an assessment of their well-being related to a 100 mm analogue scale. The assessment (a) was: How did you feel during the day? The extremes of the scale were Tired (00) and Fresh (100). In the morning the subjects were allowed to wake naturally, and 0.5h after awakening completed four assessments. The assessments and the extremes of the 100 mm analogue scales were B: I slpet, very poorly-very well, C: Now I feel, very sleepy-wide awake, D: I fell asleep, never-immediately and E: After I fell asleep I slept, very badly-very well. In each case a favourable response tended toward the 100 extreme of the scale.

Drug or placebo was ingested on the third night only, i.e. first night in the sleep laboratory. On each occasion the subject ingested two identical capsules. They were taken with water at the set time between 2300 and 2330h (lights out). No capsules were ingested on the fourth night, i.e. second night in the sleep laboratory, and this night (recovery night) was used to observe residual effects of the drug on sleep. Three ingestions of placebo were used to determine whether any trend in sleep measures occurred during the study. The study was double blind.

Recordings were made with silver-silver chloride electrodes filled with electrode jelly, and applied to the skin with colloidin. The scalp was abraded to improve electrical contact, and a resistance of less than 10 kΩ was maintained throughout each night. The three electroencephalographic (EEG) channels were recorded from the frontal (F_1-F_7), patieto-temporal (P_1-T_5) and parieto-occipital (O_zP_z-O_3) regions. The electrodes were placed according to the 10-20 system (Jasper, 1958), and the intervening site was selected to reduce subject discomfort and to ensure an artifact free recording (Williams, Karacan & Hursch, 1974). The electromyogram (EMG) was recorded from the submental musculature, and electro-oculograms (EOG) were recorded from the right eye-nasion and the left eye-nasion. A Grass 8-10 EEG machine was used. It was situated in an adjoining room, and the recording paper was run at 10 mm/s throughout the night. The half amplitude frequency response for the EEG recordings was 0.07 to 40 Hz; for the EMG recordings it was 2.5 to 90 Hz with a selective 50 Hz notch filter, and for the EOG recordings it was 0.5 to 30 Hz.

Fig. 5

Experimental design for effect of drugs on sleep in man



Each sleep record was scored independently into 30s epochs by two analysts. The analysis of the sleep stages was carried out according to the scheme of Rechtschaffen & Kales (1968), with the recommendations of Williams et. al. (1974) for epochs between obvious sleep stages. Differences in the annotation of sleep stages between the analysts were resolved, but did not occur in more than 3% of the epochs analysed. Using the sleep stage epochs, each night's sleep was analysed for various measures (Williams et. al., 1974). The coefficient of variability (s.d. x 100/mean) of each measure (C/V) was used as a preliminary criterion to decide whether an analysis of variance was appropriate. The arbitrary level was 50%, and if the value was above 50% a non-parametric method was used. The Friedmann two-way analysis of variance was the initial approach, and with a general effect of the drugs the Wilcoxon Signed-Ranks Matched-Pairs test was used. If an effect was not shown by the Friedmann test, but any effect of the drugs was in the same direction, the data for the drugs were combined to reduce variability and a differential t test carried out for the first night only. Sleep onset latencies and awakenings were tested against the hypothesis that the distribution about certain critical values was equal using the binomial test. With this approach it was possible to show whether the drugs reduced individual values. The subjective assessments were analysed by analysis of variance, and a correlation matrix between the EEG measures and subjective assessments calculated.

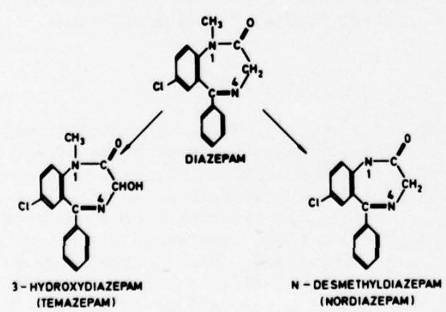


Fig. 6

Structural formulae of diazepam and its principal metabolites

	Diazepam 5mg	Diazepam 10mg	Nordiazepam 5mg	Nordiazepam 10mg	Temazepam 10mg	Temazepam 20mg
Increased total sleep time		(*)	*	***	(*)	* *
Reduced sleep onset latency	* *	* *	***	***	***	***
Reduced latency to stage 3			*	*		
Increased latency to REM sleep						***
Reduced awake (stage 0)	*	*		*	*	*
Reduced drowsy (stage 1)				***	* *	* *
Increased stage 2				*	*	*
Reduced stage 3 + 4						

Table 3

	DIAZEPAM (10mg)		TEMAZEPAM (10mg)		NORDIAZEPAM (10mg)	
	INGESTION NIGHT	RECOVERY NIGHT	INGESTION NIGHT	RECOVERY NIGHT	INGESTION NIGHT	RECOVERY NIGHT
INCREASED TOTAL SLEEP TIME	*		*		***	
REDUCED AWAKE ACTIVITY (STAGE 0)	*		*		*	*
REDUCED DROWSY ACTIVITY (STAGE 1)			**		***	
INCREASED STAGE 2			*		*	**
REDUCED STAGE 3+4						**

Table 4

Results (Tables 3& 4)

Diazepam (5 & 10 mg)

The effect of diazepam was limited to the night of ingestion. There were increases in total sleep time with 10 mg diazepam (P = 0.05). For the night of ingestion sleep onset latencies were shortened and awakenings were reduced. The low and high dose of the drug reduced the duration (min) of stage 0 sleep (P = 0.01). There were no effects on the other stages of sleep. The subjects reported an improved sense of well-being during the day after ingestion of diazepam.

Nordiazepam (5 & 10 mg)

Effects on total sleep time were limited to the night of ingestion. There were increases with 5 & 10 mg nordiazepam (P = 0.05 and 0.001 respectively). Sleep onset latencies were shortened and awakenings to stage 0 activity was reduced. The latency to stage 3 was reduced by 5 & 10 mg nordiazepam (P = 0.05). There were no effects of 5 mg nordiazepam on the duration (min) of sleep stages. 10 mg nordiazepam reduced the duration of stage 0 and stage 1 activity, and there were increases in stage 2. Reduced stage 1 and increased stage 2 sleep were observed during the recovery night. No effects were observed with stage 3, but there was evidence that stage 4 activity was depressed on the recovery night. No effects were observed on REM sleep. The effect of nordiazepam (10 mg) modified sleep for about 28-30h after ingestion. With nordiazepam subjects as a group reported improved sleep but subjective assessments of well-being were not altered.

Temazepam (10 & 20 mg)

The effect of 10 & 20 mg temazepam on sleep was restricted to the night of ingestion. There was no change in total sleep time with 10 mg temazepam, but with 20 mg total sleep time was increased (P = 0.01). Sleep onset latencies and awakenings were markedly reduced. Temazepam reduced the duration (min) of stage 0 (P = 0.05) and stage 1 (P = 0.01) sleep, and the effect on stage 1 was seen during each two hourly interval of sleep (P + 0.05). No effects were observed with stage 3, 3+4 and REM sleep, except that the appearance of the first REM period was delayed with the 20 mg dose (P = 0.001). The subjects as a group reported improved sleep, but subjective assessments of well-being were not altered.

The effect of these drugs on sleep stages and their persistent effects during the second night are given in the tables. It would appear that nordiazepam which has a plasma half life of around 2 days leads to persistent effects on sleep and there is evidence that performance is impaired during the intervening day (Tansella et. al., 1974). On the other hand the effects of diazepam and temazepam on sleep appear to be useful and there is no evidence of a persistent effect on sleep extending to the second night. Preliminary studies on the residual effects of these drugs on performance suggest that useful dose ranges may be without adverse sequelae. It would therefore appear that diazepam and its hydroxylated metabolite, temazepam, may be particularly useful in the management of sleep disturbance in aircrew.

Effectiveness of drugs for day time sleep

The usefulness of the hypnotic is usually assessed by its effect on nocturnal rest, though, with the irregular work of many present day occupations it is also important to have information on the effectiveness of hypnotics at other times of the day. In many occupations, such as aviation, it is often necessary to rest when the desire to sleep may not be optimum, and it cannot be assumed that hypnotics acceptable for use at night would be equally suitable for use at other times of the day. Indeed, the response of man to many drugs varies with his circadian rhythm, and it is likely that hypnotics would exhibit variations in activity relevant to the management of sleep disturbances in those with irregular work. The previous studies on the effects of drugs on sleep and on performance in man indicate that diazepam and 3-hydroxy-diazepam (temazepam) may be particularly useful with aircrew. In these studies the effect of diazepam and temazepam as hypnotics when the circadian desire to sleep may not be optimum was investigated. These studies are still in progress but they indicate that the effectiveness of the hydroxylated derivative of diazepam (temazepam) is much less for sleep during the day than that of diazepam, whereas diazepam is less effective for sleep at night than that of temazepam. The summary of the results are given in Table 5 and the cumulative duration of sleep stages 2, 3, 4 and REM are provided in the sleepolarograms in Figs. 7 & 8. It can be seen that the sleep time (i.e. total stage 2, 3, 4 and REM) for both day time and night time sleep increase up to the first 3 hours in bed. At the end of the 3 hour period the total sleep time for day time sleep is just over 130 minutes whereas that for night time sleep is about 150 minutes. The interesting point of the effect of drugs at this time with the day time sleep is that day time sleep with 10 mg temazepam or 5 mg diazepam produces the same total sleep as that which would be expected with night time sleep without drugs. On the other hand the period from 3-6 hours presents very different picutres

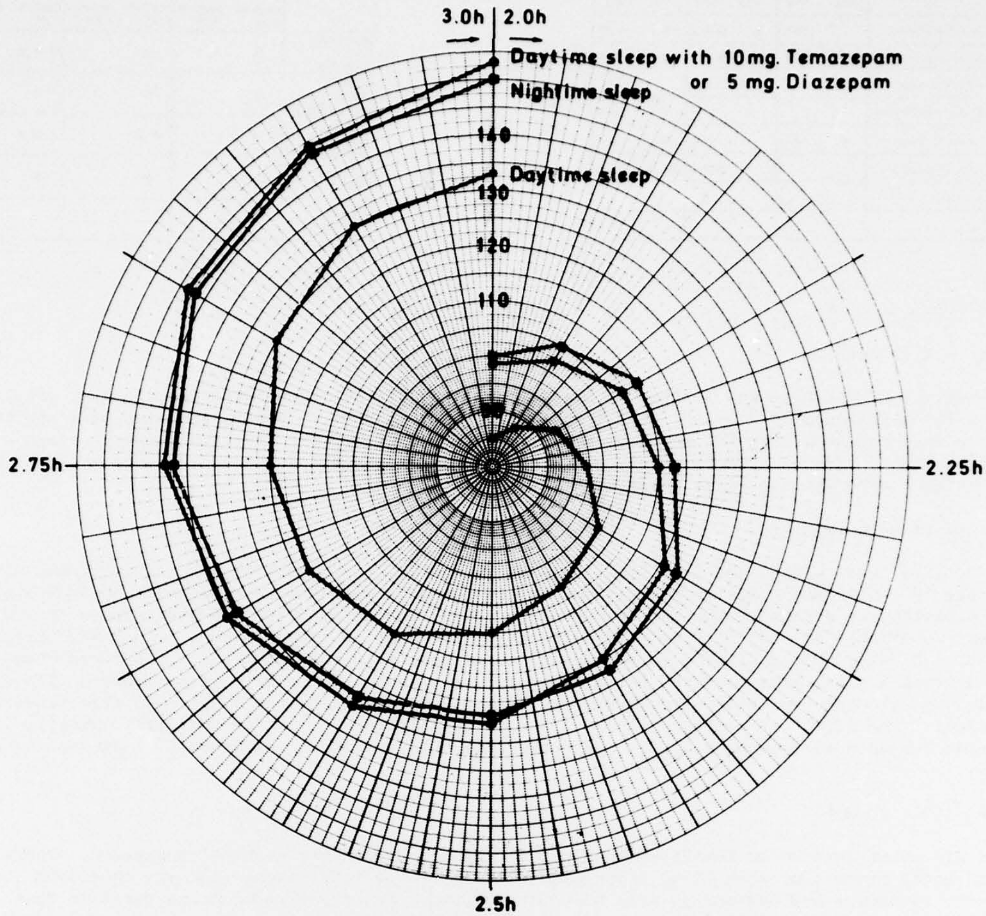


Fig. 7

Sleepolarogram: change in duration of the
combined sleep stages 2, 3, 4 and REM for 2.0-3.0h of an afternoon sleep from 1400h

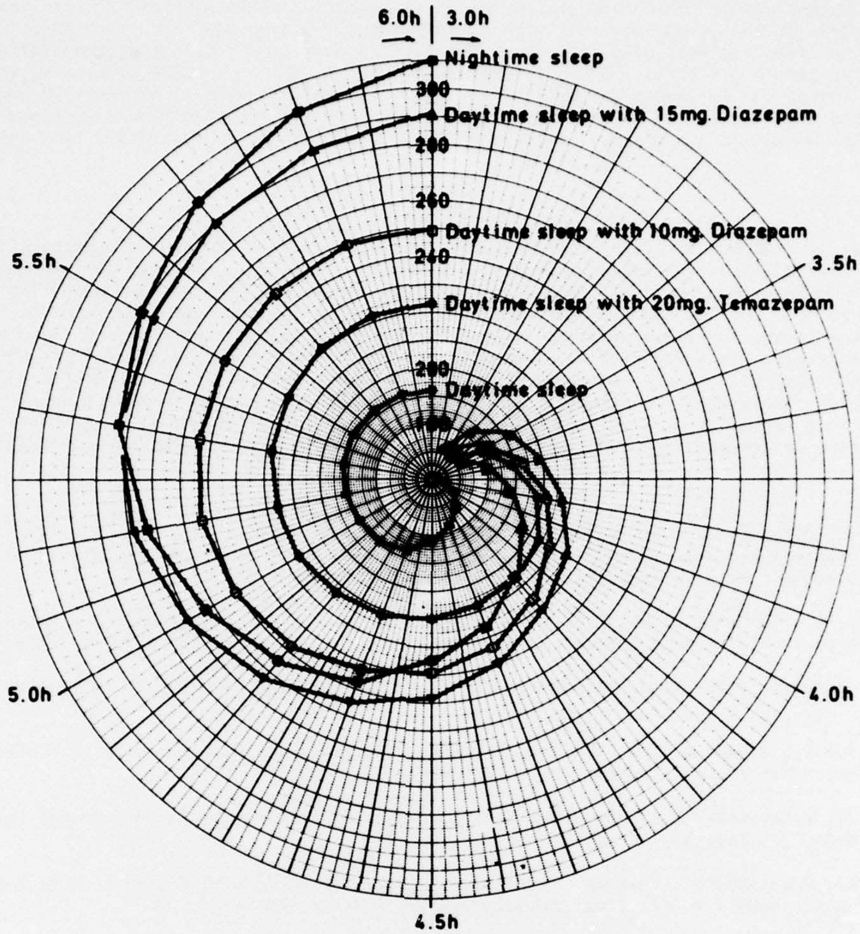


Fig. 8

Sleepolarogram: change in duration of the
combined sleep stages 2, 3, 4 and REM for 3.0-6.0h of an afternoon sleep from 1400h

	Night time sleep		Day time sleep	
	Diazepam 10mg	Temazepam 10mg	Diazepam 10mg	Temazepam 10mg
Increased total sleep time	(*)	* * *	*	
Reduced sleep onset latency	* *	* * *	*	
Reduced latency to stage 3		*		
Increased latency to REM sleep			*	
Reduced awake (stage 0)	*	*	*	*
Reduced drowsy (stage 1)		* * *	* *	
Increased stage 2		*		

Table 5

Significant changes in certain sleep measures with 10 mg diazepam
and temazepam for night time and day time sleep

concerning the effectiveness of these drugs. Over this period of time the total amount of sleep obtained during the day has increased to 190 minutes but has remained constant during the last hour and a half, whereas with night time sleep there is an increasing amount of sleep throughout the whole of the 6 hour period and that by the end of the 6 hour period the total amount of sleep is about 310 minutes. An analysis of the effectiveness of the drugs show that with 20 mg temazepam during day time sleep there has been a useful increase in sleep but this occurred during the first 4 hours and that during the last 2 hours of the day time sleep period there was little, if any, increase. On the other hand with 10 mg diazepam the amount of sleep during the day increases up to the 5 hour interval and with 15 mg diazepam the amount of sleep is increasng even toward the end of the 6 hour period. It is of interest that with the 15 mg dose diazepam the total amount of sleep approximates that which would be obtained at night time without use of drugs.

CONCLUSIONS

Though these studies are not yet complete a picture is emerging of the use of hypnotics for aircrew. It would appear that diazepam and temazepam are to most promising drugs. However, it is likely that the dose range which would be most suitable for diazepam would 5-10 mg whereas the dose range for temazepam is likely to be 10-20 mg. Further studies need to be carried out on the residual effects of these two drugs on performance and on their effects on sleep at unusual times of the day. However, it would appear practical to use drugs for aircrew with sleep disturbances and that the use of these drugs would not be complicated by residual effects on performance. As far as aerospace operations are concerned it is suggested that the judicious use of hypnotics may be of particular use during times of adaptation to the new environment, and may be particularly important in the management of flight crews when the duration of the space operation is limited to a few days and the most economical use of time is important.

REFERENCES

1. Barzaghi, F., Fournex, R. & Mantegazza, P. Pharmacological and toxicological properties of clobazam (1-phenyl-5-methyl-8-chloro-1,2,4,5-tetra-hydro-2,4-diketo-3H-1,5-benzodiazepine), a new psychotherapeutic agent. Arzneimittel-Forsch., 23, 686-686 (1973).

2. Berry, P.A., Burtles, R., Grubb, D.J. & Hoare, Margaret V. An evaluation of the effects of clobazam on human motor co-ordination, mental activity and mood. Br. J. clin. Pharmac., 1, 346P (1974).

3. Bond, A.J. & Lader, M.H. Residual effects of hypnotics. Psychopharmacologia (Berl.), 25, 117-132 (1972).

4. De Silva, J.A.F., Koechlin, B.A. & Bader, G. Blood level distribution patterns of diazepam and its major metabolite in man. J. pharm. Sci., 55, 692-702 (1966).

5. Hartman, B.O. & McKensie, R.E. Hangover effect of secobarbital on simulated pilotage performance. Aerospace Med., 37, 1121-1124 (1966).

6. Jäättelä, A., Männistö, P., Paatero, H. & Tuomisto, J. The effects of diazepam or diphenydramine on healthy human subjects. Psychopharmacologia, 21, 202-211 (1971).

7. Kornetsky, C., Vates, T.S. & Kessler, E.K. A comparison of hypnotic and residual psychological effects of single doses of chlorpromazine and secobarbital in man. J. Pharmac. exp. Ther., 127, 51-54 (1959).

8. Linnoila, M. & Mattila, M.J. Drug interaction on psychomotor skills related to driving: diazepam and alcohol. Eur. J. clin. Pharmac., 5, 186-194 (1973).

9. Malpas, A., Rowan, A.J., Joyce, C.R.B. & Scott, D.F. Persistent behavioural and electroencephalographic changes after single doses of nitrazepam and amylobarbitone sodium. Br. med. J., 2, 762-764 (1970).

10. McKensie, R.E. & Elliott, L.E. The effect of secobarbital and d-amphetamine on performance during a simulated air mission. Aerospace Med., 36, 774-779 (1965).

11. Montagu, J.D. Effects of diazepam on the EEG in man. Eur. J. Pharmac., 17, 167-170 (1972).

12. Rieder, J. Plasma levels and derived pharmacokinetic characteristics of unchanged nitrazepam in man. Arzneimittel-Forsch., 23, 212-218 (1973).

13. Schwartz, M.A., Postma, E. & Gaut, Z. Biological half-life of chlordiazepoxide and its metabolite, demoxepam, in man. J. pharm. Sci., 60, 1500-1503 (1971).

14. Tansella, M., Zimmermann Tansella, Ch. & Lader, M. The residual effects of N-desmethyldiazepam in patients. Psychopharmacologia (Berl.), 38, 81-90 (1974).

15. Von Felsinger, J.M., Lasagna, L. & Beecher, H.K. The persistence of mental impairment following a hypnotic dose of a barbiturate. J. Pharmac. exp. Ther., 109, 284-291 (1953).

16. Williams, R.L., Karacan, I.I. & Hursch, Carolyn J. Electroencephalography (EEG) of human sleep: clinical applications. New York: John Wiley & Sons (1974).

This paper is based on work by the authors published in the British Journal of Clinical Pharmacology.

1. Human performance after a barbiturate (heptabarbitone). R.G. Borland & A.N. Nicholson. Br. J. clin. Pharmac., 1, 209-215, 1974.

2. Comparison of the residual effects of two benzodiazepines (nitrazepam and flurazepam hydrochloride) and pentobarbitone sodium on human performance. R.G. Borland & A.N. Nicholson. Br. J. clin. Pharmac., 2, 9-17, 1975.

3. Behavioural sequelae of methaqualone in man and in the monkey (Macaca mulatta). R.G. Borland, A.N. Nicholson & C.M. Wright. Br. J. clin. Pharmac., 2, 131-141, 1975.

4. Immediate effects on human performance of a 1,5-benzodiazepine (clobazam) compared with the 1,4-benzodiazepines, clordiazepoxide hydrochloride and diazepam. R.G. Borland & A.N. Nicholson. Br. J. clin. Pharmac., 2, 215-221, 1975.

5. Effect of N-desmethyldiazepam (nordiazepam) and a precursor, potassium clorazepate, on sleep in man. A.N. Nicholson, B.M. Stone, C.H. Clarke, & H.M. Ferres. Br. J. clin. Pharmac., In Press, 1976.

6. Effect of diazepam and fosazepam (a soluble derivative of diazepam) on sleep in man. A.N. Nicholson, B.M. Stone & C.H. Clarke. Br. J. clin. Pharmac., In Press, 1976.

7. Effect of a metabolite of diazepam, 3-hydroxydiazepam (temazepam), on sleep in man. A.N. Nicholson & B.M. Stone. Br. J. clin. Pharmac., In Press, 1976.

DISCUSSION

E.Lauschner: What information do you have on the possible effects of repeated ingestion of diazepam on performance?

A.N.Nicholson: We do not have such information, but I agree it is needed. This is a possible disadvantage in the use of diazepam, because of the possible accumulation of its long acting metabolite, nordiazepam, which have a half life exceeding 2 days. On the other hand, the other metabolite of diazepam, temazepam, does not have a metabolite with a long plasma half life, and so none possess an advantage over diazepam, at least in this respect.

R.Auffret: Pour mesurer la performance vous utilisez un test de poursuite:

(1) Quelle est la durée de ce test?

(2) Quelle est la meilleure durée d'un test de poursuite pour effectuer l'évaluation des médicaments hypnotiques?

A.N.Nicholson: The duration of tracking is 10 min.

During the first 100 s. the subject reaches plateau performance, and the mean performance over the next 500 s. is taken as the performance score.

K.E.Klein: In your Figure 4, performance after having been impaired for many hours, improved, and finally was higher than your premedication reference. Is this performance increase significant and is it a practising effect or caused by other reasons?

A.N.Nicholson: Yes. In all studies we have observed enhanced performance after recovery, and the appearance of enhanced performance would appear to be related to the brief life of the drug. The explanation of the enhancement is not obvious, but may be related to a rebound phenomenon secondary to central nervous system depression or possibly to some effect related to sleep.

SPACE AGE HEALTH CARE DELIVERY

Walton L. Jones, M.D.
Acting Director
Office of Occupational Medicine
NASA HEADQUARTERS
Washington, D.C. 20546

Space age health care delivery is being delivered to both NASA astronauts and employees with primary emphasis on preventive medicine. The program relies heavily on comprehensive health physical exams, health education, screening programs and physical fitness programs. Medical data from the program is stored in a computer bank so epidemiological significance can be established and better procedures can be obtained.

Besides health care delivery to the NASA population, NASA is working with HEW on a telemedicine project STARPAHC, applying space technology to provide health care delivery to remotely located populations. The military services are also experimenting with telemedicine projects, such as the Navy's RMDS. Both civilian and military telemedicine projects are using allied health personnel to extend the medical services of the physician.

A greater emphasis on preventive medicine and growing awareness of the importance of occupational health mark the epoch of space age health care delivery. Health care of this type relies heavily on comprehensive health physical exams and health education, as well as primary screening and physical fitness programs.

NASA astronauts and employees are receiving space age health care delivery through an extensive employee health program that emphasizes the prevention, diagnosis of disease, treatment and care of illnesses and injuries caused or aggravated by the work environment. Astronauts receive annual comprehensive physical examinations. Other NASA employees are examined on a voluntary basis.

The complete physical examination of the NASA Occupational Medicine Program consists of:

(a) Height, weight, blood pressure;

(b) Blood chemistry, hematology, and urinalysis;

(c) Hearing acuity test (automatic audiometry using ARJ-4 Rudmose automatic and the IAC-1200 Audiometric test room with sound attenuation of 20 dBs.) ANSI 1969 International Hearing Standard;

(d) Visual acuity test and tonometry;

(e) Vital capacity;

(f) Chest X-ray;

(g) Resting electrocardiogram (as well as dynamic EKG where patient is monitored for six hours during work period to identify any rhythm irregularities prior to the treadmill exam) (See Figure 1);

(h) Treadmill or exercise electrocardiogram (using modified Bruce protocol) (See Figure 2);

(i) Proctosigmoidoscopy;

(j) Pelvic examination for women (including Papanicolaou's stain);

(k) Physical examination and discussion of findings of the total examination by the physician.

The results of this complete examination are recorded in a computer data bank (refer to Figure 3 for this format). If there are no significant medical findings from the complete physical examination, a thorough screening by laboratory, X-ray and EKG are given on the second and third year. For women, an annual Papanicolaou test and breast examination are given. Personnel are given additional tests, or may be examined at more frequent intervals, if medical findings, hazards in the work environment, or job-related conditions warrant this evaluation.

The NASA Occupational Medicine data system is designed for NASA-wide application. The goal of the system is to provide a means of rapid storage and retrieval of information for use by NASA medical staffs in reviewing workload data, establishing manpower and staffing requirements, and in analysis of findings from physical examinations, injury and illness visits. The medical data are used for periodic review of program requirements and the need for changes in diagnostic procedures, examination intervals, and in studies of epidemiological trends in illness. They are also used for analyzing the relationship between potential hazards in the work environment and the evolution of illness and disease.

In addition to promoting preventive medicine through extensive physical examinations, NASA realizes the importance of preventive health education and recognizes primary screening programs as a means to this end. Besides informing the population of the nature and threat of a disease, specialized mass screenings can serve as a useful purpose.

For example, recognizing the importance of hypertension detection; as national estimates show that 23 million Americans have high blood pressure and only half of these people are aware of their condition; NASA sought to raise its employees health awareness to this issue. In an effort to encompass both purposes, NASA Headquarters Office of Occupational Medicine held its first hypertension screening program and advocated that mass screening programs be held in all its centers during this past May, which was designated by the Department of Health, Education and Welfare as National Hypertension Awareness Month.

During May, NASA Headquarters screened over one third of its 1,500 employees. Ten percent were found to have elevated readings at the time of the screening. These individuals were referred to their private physician for verification and if indicated proper therapy. These people are also being followed-up by NASA examinations, at six-month intervals.

A special examining booth was set up at a central location, so that any employee passing by could stop in for what was billed as a two-minute check of his blood pressure with spaceage technology, (See Figures 4 and 5). Blood pressures were taken by a nurse using a semi-automatic testing system, known as the Vital Signs Monitor that prints out the blood pressure and heart rate in digital display. The subject's sex, age, height, weight, smoking habits, blood pressure, and heart rate were entered into a computer. In a few seconds, the subject received a printout (See Figure 6) which told him the extent to which he was at risk of developing a cardiovascular problem within the next eight years based on the data of the Framingham studies on cardiovascular disease.

The computer program used, written in FORTRAN IV, calculated the risk of cardiovascular disease by analyzing systolic blood pressure through risk equations based on a subject's sex, age and smoking habits:

$$Y = \sum_{t=0}^{2} a_t X^t$$

where Y is risk of developing cardiovascular disease within the next eight years per 1000, X is the systolic blood pressure value, and a_t represents a set of parameters.

Besides stressing preventive health education and serving as a detection/referral/follow-up program, the hypertension project facilitated data collection which is stored in the NASA Medical Data Base to be reviewed for epidemiological significance.

Since physical fitness is directly related to good health, NASA employees may take part in a physical fitness laboratory program. Personnel using various exercise equipment (See Figure 7) progress through a supervised exercise program in a manner which provides optimal work loads. These equipments are: treadmill, punching bag, bicycle ergometer, wall weights, jumping rope, sit-ups, rowing machine, beam walk and medicine ball. In addition to the gymnasium activities, intercenter competitive jogging contests are held where employees compete in different age categories.

Each person's progress is based on the change in his resting pulse rate after each work-out session. The records of each person's exercise program are forwarded to the facility physician and reviewed at the time of his physical examination.

Another important contribution by NASA to spaceage health care delivery is the use of advanced technology from the space program. One of these areas is telemedicine, a system which gives physicians (without physically being present) the capability to administer quality health care to patients in remote areas by using telecommunications and teams of allied health personnel.

To prepare for the time when health care will be required on a deep space mission, NASA is conducting a demonstration project in conjunction with the Department of Health, Education, and Welfare on delivery of health care to remote areas here on earth using space technology. Many similarities exist between administering quality health care in a spacecraft and administering the same care to a remote population on earth. The long duration manned mission will likely require that some members of the crew be specially trained as well as be able to consult with the ground mission control center and obtain special assistance and/or supervision to assure quality care. The results of special tests, X-rays, ECGs, video pictures of magnified fields from slides, video pictures of the patient, etc., will be transmitted and evaluated by specialists in a medical center.

This remote health care program is titled, "Space Technology Applied to Rural Papago Advanced Health Care" (STARPAHC). The physical setting for STARPAHC is the Papago Indian Reservation which covers 4,300 square miles in the Sonora Desert, west of Tucson and south of Phoenix, Arizona, where 8-10,000 permanent residents live in 75 villages, and another 2-4,000 tribal members return for medical treatment.

The Indian Health Service provides health care on the reservation through a 50-bed hospital, a part-time fixed outpatient clinic, and a mobile health unit (MHU) (See Figure 8) that visits the outlying villages on a weekly schedule. The MHU is equipped with examining rooms, X-ray and laboratory facilities and paramedical personnel.

The Indian Health Hospital in Phoenix provides additional facilities and medical specialists that can be reached by the primary physician (located at Sells) for consultations. A computerized health information system in Tucson maintains the health records of the Indians using the IHS facilities. (See Figure 9).

STARPAHC provides two-way audio, video and data communications linking the diverse facilities on the reservation to permit real time exchange of information between the paraprofessional practitioners who staff the clinics and the physicians at a central

hospital. The system also provides telephone line voice and slow-scan television links to specialists in a larger hospital.

Now at its one-year operational evaluation point, STARPAHC has increased its use of telecommunications (approximately 71% from May 1975 to January 1976) and decreased the time it takes per transmission.

In the past year, 3,998 telecommunications (76 failures) were made which resulted in 98.1% efficiency. During the first 10 months of its operation, the Mobile Health Unit lost one day of scheduled service due to maintenance. Community acceptance of the program has been outstanding, and patient loading on the MHU at each village stop has reached saturation proportions; i.e., 18 to 27 patients/day (maximum design estimate, 12 to 15/day).

As per usual there were some problems with the equipment at the outset of the project. One of the problems STARPAHC experienced in the past year was computer availability. Down time, due to voltage irregularities was 11.1%. These irregularities have now been corrected with a power conditioning system.

In terms of cost effectiveness, in its first six months of operation, the recurring cost/patient was $48.09 and during its second six month period, the recurring cost was cut to $43.49/patient, for a 10% reduction. It may be that the most significant finding from the first year evaluation is that lesser trained personnel may be utilized to provide high quality health care. STARPAHC capabilities afford many benefits to education and welfare programs, as well as primary medical care. The capability to communicate (over video and audio links) is being used with the people of remote villages will enable teaching and instruction to support environmental health, sanitation, nutrition, and disease control.

The use of communication systems to provide health-care delivery to remote areas is not new, although it is a subject receiving rapidly increasing attention. The military services are also experiencing a shortage of physicians due to various reasons. The Navy, for example, is using physicians more in hospitals rather than aboard ships. As a result, there will be more extensive use of Navy corpsmen to provide total shipboard health care.

To develop a communications link between physician and corpsman, the Biosystems engineering Group of the Naval Electronics Laboratory Center (NELC) is performing a feasibility study to test the concept of a Remote Medical Diagnosis System (RMDS). The ability to properly diagnose and determine appropriate treatment for illnesses and injuries is a critical part of any medical program. Many of the medical cases aboard ship are presently being diagnosed by corpsmen and given minor or emergency treatment without requiring the services of a physician. However, there are cases in which a corpsman or a physician may be uncertain of a medical diagnosis, or in which a patient's condition may necessitate a decision as to whether or not to air-evacuate him. A Remote Medical Diagnosis System would then enable the corpsman or physician to have a direct communication link with a medical specialist (located on board another ship or ashore) to provide a remote diagnosis and prescribe the proper treatment. Such a system must be able to transmit medical records, clinical data, and accompanying voice transmissions. It may also be desirable to have the capability to transmit information visually and ultimately provide a computer interface for record retrieval and storage.

Through the use of telemedicine and the technologies associated with it, in communications and data systems, it is reasonable to predict an upgrading of quality health care delivery to people of remote areas, civilian or military. In addition, valuable information gleaned from STARPAHC will promote effective health-care systems for future manned spacecraft, in terms of level of medical talent required, protocols, techniques, data formats, equipment needs, training needs, man/machine interface and personnel interactions (medical and nonmedical).

On the basis of the tests performed thus far, the concept of remote medical diagnosis as applied to U. S. Navy ships has been demonstrated. The potential usefulness of such a system cannot be fully demonstrated without the use of equipment that represents the most recent technological advances in slow-scan imagery and is capable of operating reliably in a shipboard environment. Consequently, the major limitations are the lack of up-to-date equipment appropriately designed for the application and the availability of a good quality, reliable communication network. The required equipment components are available and need only be integrated into the proper configuration.

Although existing Navy communication networks provide a capability for any Navy ship to access a land-line connection to a medical facility ashore from most locations in the world for an emergency situation, for a remote medical diagnosis system to be used on a more regular and routine basis, several specially-assigned hf, vhf, and uhf frequencies are a necessity in order to select the best frequency available at the time. For the future, however, satellite voice channels can provide a high-quality, low error-rate, long-haul communication medium for the effective operation of the Navy's Remote Medical Diagnosis System.

Space age health care delivery focuses on preventive medicine rather than acute medical care or symptomatic medicine. Preventive health education is highlighted to promote individual health awareness. The value of employee health programs can be measured by reducing job-time loss and treatment costs. Besides boosting the morale of the individual; if an early disease state is found, treatment can be started before irrepairable harm has occurred. Beyond local employee populations, remote civilian populations can receive better and more extensive health care than before through improved technologies and data systems borrowed from space age technology. The efficacy of using allied health personnel to provide quality health care to both civilian and military populations is being demonstrated by such projects as STARPAHC and RMDS. All these efforts represent a positive step towards providing higher quality health care to more people, a goal of international scope.

1. Eli Lilly Pharmaceutical Company, Medifacts, Indianapolis, Indiana, 1974.

2. Kannel, William B. and Gordon, Tavia. The Framingham Study: An Epidemiological Investigation of Cardiovascular Disease. DHEW Publication No. (NIH) 74-478. Washington, D.C., U.S. Government Printing Office, December 1973.

3. Merck & Co., Inc., The Merck Manual, 12th Edition, Rahway, New Jersey, 1972.

4. Sanders, James H., SOLVE: A Computer Program for Fitting Mathematical Models to Known Data Sets. BioTechnology, Inc., Falls Church, Virginia, 1975.

5. Belasco, Norman and Pool, Samuel L., STARPAHC - The Second Operational Progress Report of a Remote Area Telemedicine System. Johnson Space Center, Houston, Texas, 1976.

6. Rasmussen, W. T. and Silva, J., Navy Remote Medical Diagnosis System. Naval Electronics Laboratory Center, San Diego, California, 1976.

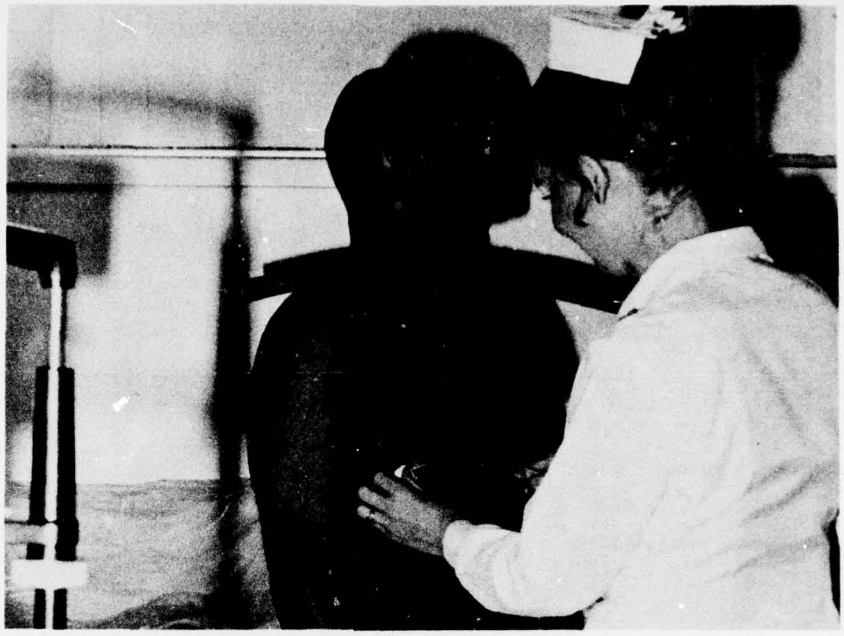
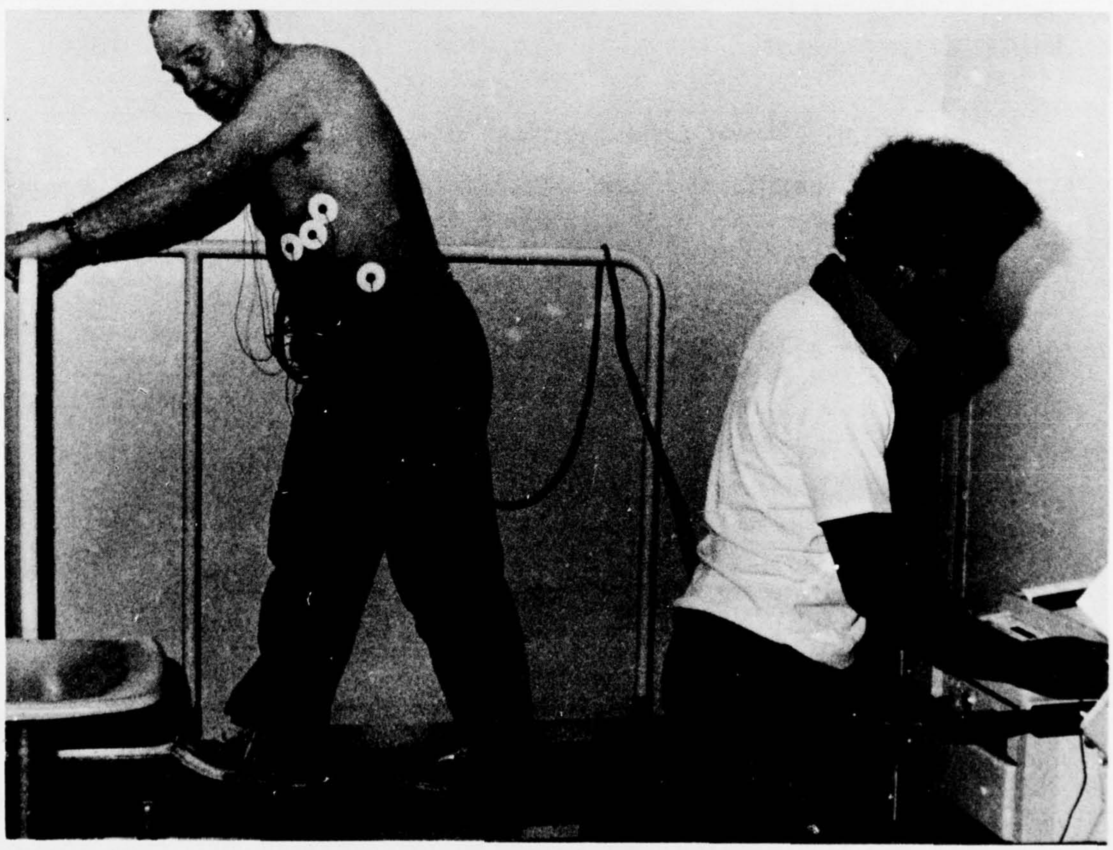


Fig. 1. Dynamic EKG monitors patient to identify any rhythm irregularities.

Fig. 2. Treadmill electrocardiogram tests patient's heart rhythm upon exercise.



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MEDICAL INFORMATION SYSTEM
HEALTH PROFILE REPORT
EXAMINATION

Sex: M DOB: 3/18/30 NCC: 63002

Medical Identification Number:

Date of Examination	4/13/76
Age	46
Height	76
Weight	191
Systolic blood pressure	114
Diastolic blood pressure	80
Pulse	070
Sigmoidoscopy	WNL
Rectal	ONL
Pelvic	
Pap Smear	
Visual Testing	WNL
Audio Testing	WNL
Tonometry	
OD	12
OS	13
Forced Expiratory Volume	122
Hematology	
HGB	14.7
HCT	44
WBC	04500
PMN	64
LYMPH	32
MONO	02
EOS	02
BASO	
ESR	05
Thyroxine (t-4)	72
Chemistry	
Glucose	70
BUN	24
Creatinine	1.4
Na^+	140
K^+	7.2
Cl^-	101

CO_2	29
Uric Acid	5.3
T. Protein	6.9
Albumin	4.1
Globulin	2.8
A/G	1.4
Calcium	9.8
Phosphate	2.9
Cholesterol	165
Trig.	71
Alk.Phos.	53
SGOT	15
SGPT	9
LDH	184
T.Bili	1.0
Urinalysis	
Sp. Gr.	1.028
PH	
Albumin	0
Glucose	0
RBC per HPF	0
WBC per HPF	01
Casts	
Cigarettes smoked per day	00

Date of Exam	Diagnoses from exam	Diagnoses from Electrocardiogram	Diagnoses from Chest x-ray
4/13/76	600 Hyperplasia of prostate	00.0 Within normal limits	00 within normal limits

Fig. 3. Computer format for NASA Health Profile Report.

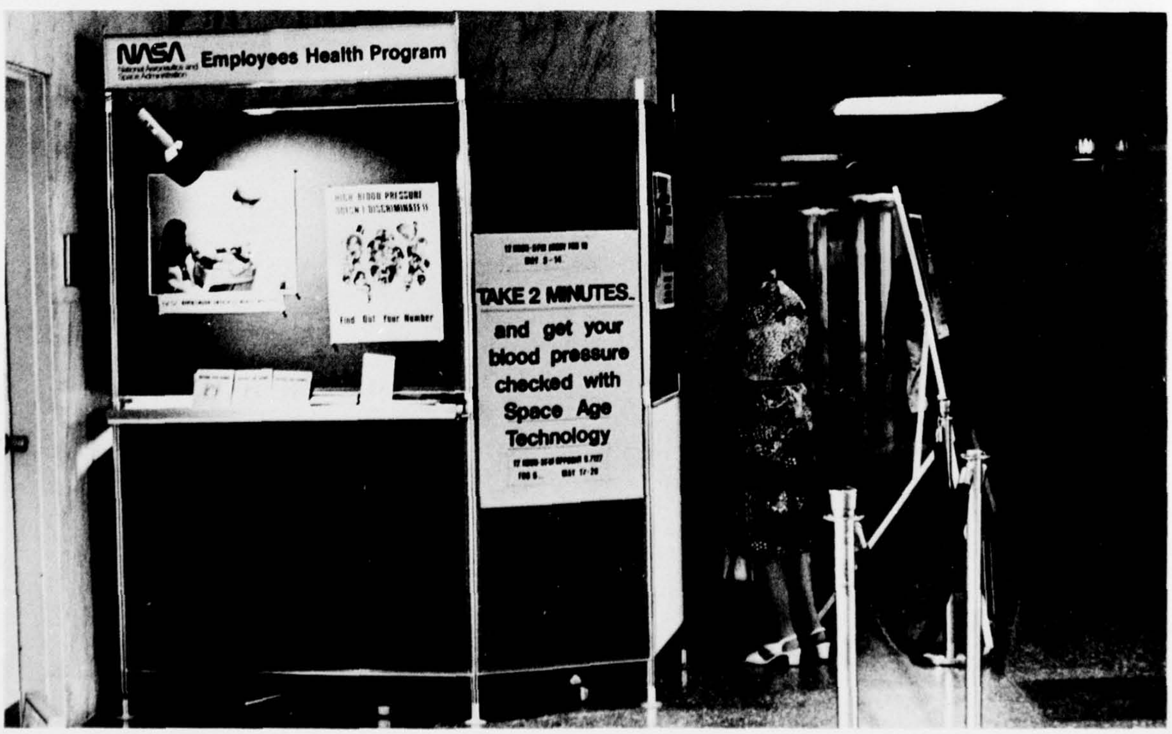


Fig. 4. Hypertension screening booth.

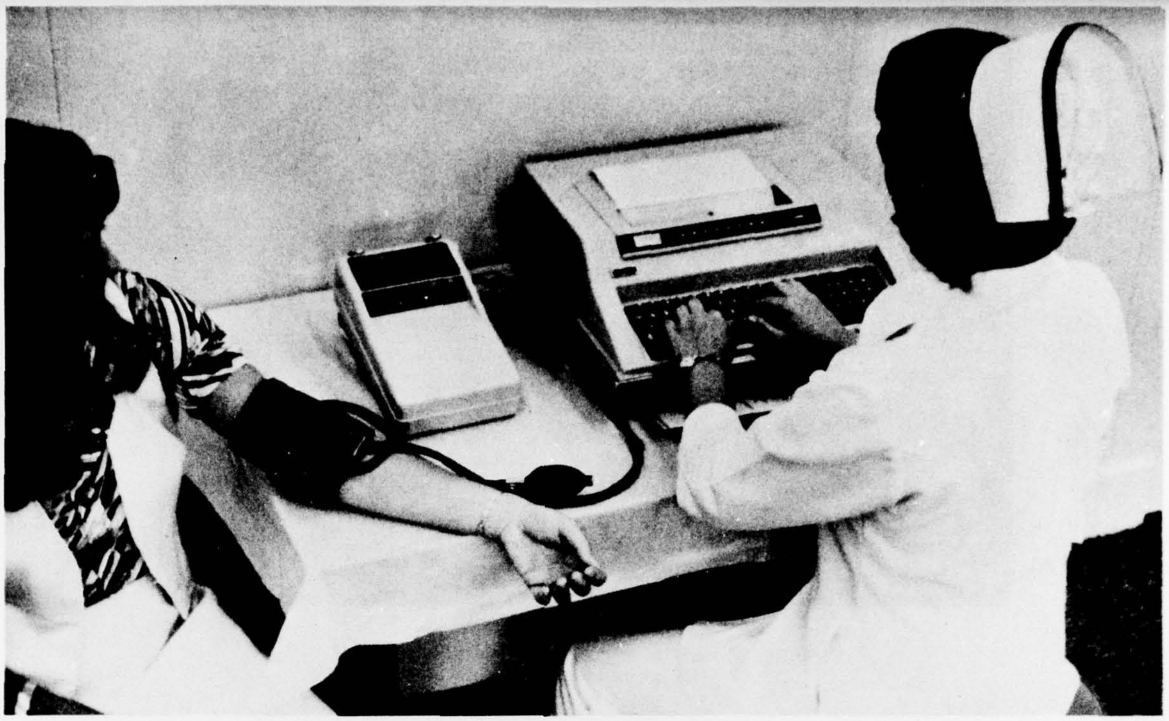


Fig. 5. Utilizing space age technology to check patient's blood pressure.

NASA INSTA-HEALTH ANALYSIS

NAME: MARY SMITH

SEX: FEMALE AGE: 60

HEIGHT: 72 INCHES WEIGHT: 120 LBS.

SMOKER? NO

BLOOD PRESSURE: 180/ 90 HEART RATE: 82

ANALYSIS:

NORMAL RANGE OF BLOOD PRESSURE FOR YOUR AGE AND SEX IS:
115/ 70 TO 175/100
YOUR RISK OF DEVELOPING A HEART OR CIRCULATORY DISEASE WITHIN THE NEXT EIGHT YEARS IS 172 IN 1000.

RECOMMENDATIONS:

YOUR BLOOD PRESSURE READING IS A LITTLE HIGHER THAN IS DESIRABLE. WE RECOMMEND YOU SEE YOUR PHYSICIAN OR VISIT THE NASA CLINIC FOR ANOTHER CHECK.

THERE ARE DEFINITE THINGS YOU MIGHT DO THAT COULD REDUCE YOUR BLOOD PRESSURE.
USING LESS SALT IN YOUR DAILY DIET WOULD BE HELPFUL.
PLEASE LET US CHECK YOU AGAIN NEXT YEAR.

THANK YOU FOR PARTICIPATING IN THE NASA HEALTH AWARENESS PROGRAM. THIS WAS PROVIDED THROUGH THE COURTESY OF THE OFFICE OF OCCUPATIONAL MEDICINE AND THE NASA HEADQUARTERS COMPUTER CENTER.

Fig. 6. Patient printout from hypertension screening program.

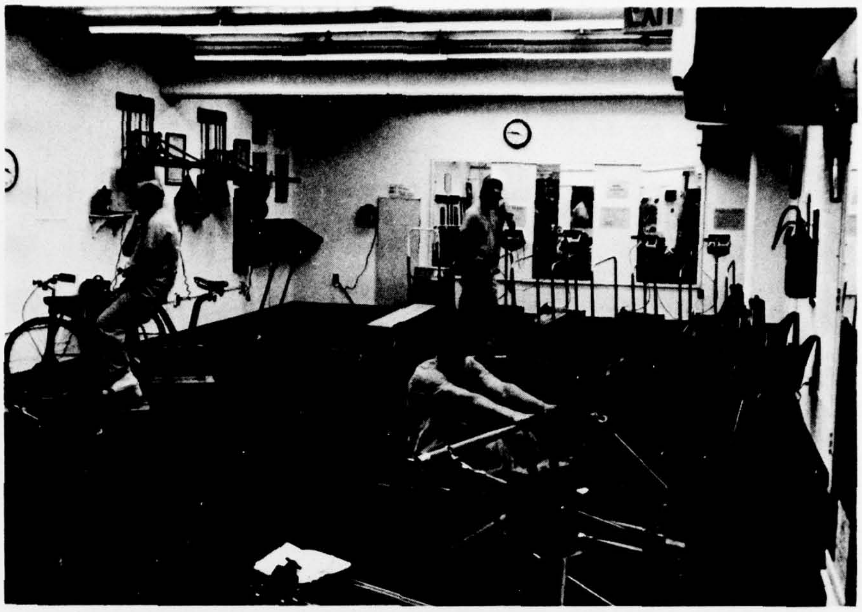


Fig. 7. NASA Employees participating in physical fitness program.

Fig. 8. STARPAHC Mobile Health Unit visits Papago Indian village.

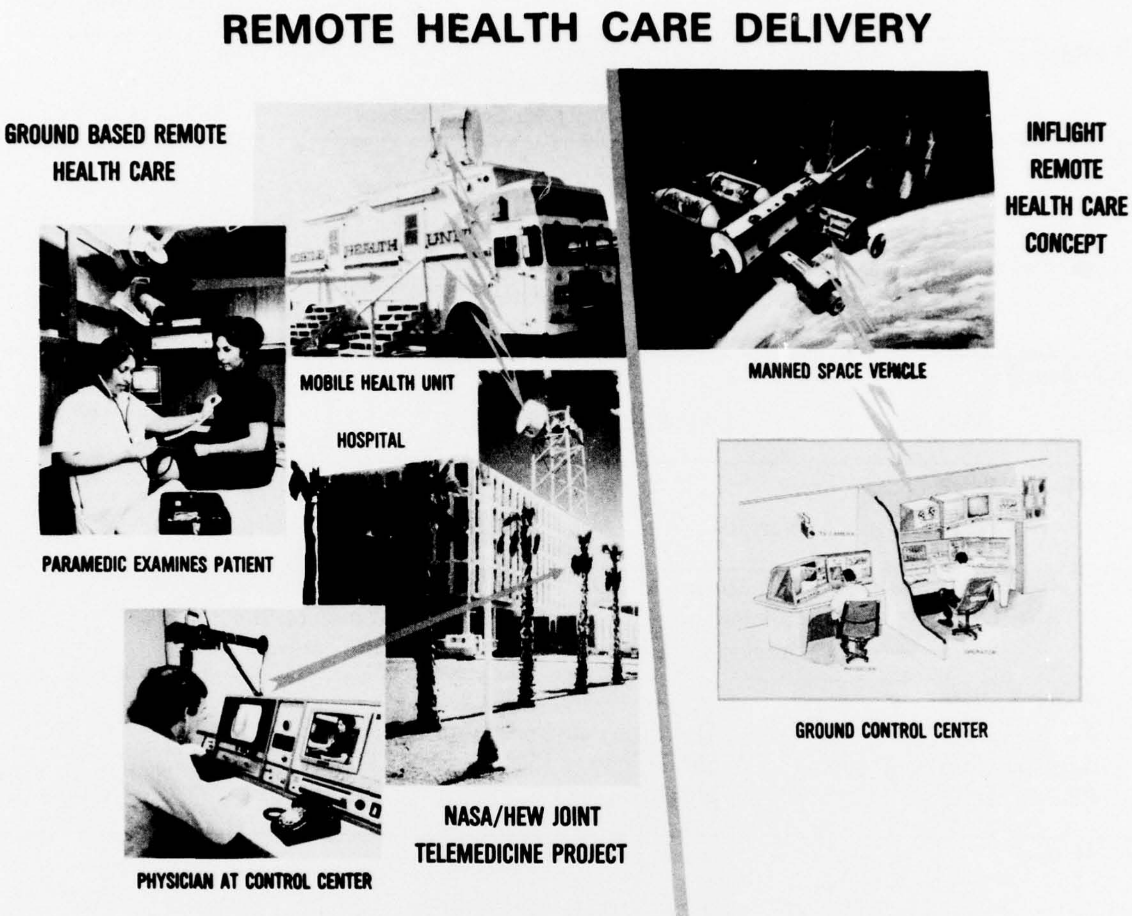


Fig. 9. Using space age technology to deliver remote health care.

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-CP-203	ISBN 92-835-0186-1	UNCLASSIFIED

5. Originator Advisory Group for Aerospace Research and Development
North Atlantic Treaty Organization
7 rue Ancelle, 92200 Neuilly sur Seine, France

6. Title

RECENT ADVANCES IN SPACE MEDICINE

7. Presented at the Aerospace Medical Panel Specialists' Meeting held in Athens, Greece, 20–24 September 1976.

8. Author(s)	9. Date
Various — Edited by: J.Colin	January 1977
10. Author's Address	**11. Pages**
Various	122

12. Distribution Statement This document is distributed in accordance with AGARD policies and regulations, which are outlined on the Outside Back Covers of all AGARD publications.

13. Keywords/Descriptors

Aerospace medicine	Spacecraft environments	Motion sickness
Aerospace environment	Psychology	Training
Bioastronautics	Weightlessness	Flight crews

14. Abstract

This publication contains 13 papers presented at a Specialists' Meeting of the Aerospace Medical Panel, held in Athens, Greece, 20–24 September 1976. A Technical Evaluation Report, in French and English, is included.

AGARD Conference Proceedings No.203
Advisory Group for Aerospace Research and Development, NATO
RECENT ADVANCES IN SPACE MEDICINE
Editor: J.Colin
Published January 1977
122 pages

This publication contains 13 papers presented at a Specialists' Meeting of the Aerospace Medical Panel, held in Athens, Greece, 20–24 September 1976. A Technical Evaluation Report, in French and English, is included.

ISBN 92-835-0186-1

AGARD-CP-203

Aerospace medicine
Aerospace environment
Bioastronautics
Spacecraft environments
Psychology
Weightlessness
Motion sickness
Training
Flight crews

AGARD Conference Proceedings No.203
Advisory Group for Aerospace Research and Development, NATO
RECENT ADVANCES IN SPACE MEDICINE
Editor: J.Colin
Published January 1977
122 pages

This publication contains 13 papers presented at a Specialists' Meeting of the Aerospace Medical Panel, held in Athens, Greece, 20–24 September 1976. A Technical Evaluation Report, in French and English, is included.

ISBN 92-835-0186-1

AGARD-CP-203

Aerospace medicine
Aerospace environment
Bioastronautics
Spacecraft environments
Psychology
Weightlessness
Motion sickness
Training
Flight crews

AGARD Conference Proceedings No.203
Advisory Group for Aerospace Research and Development, NATO
RECENT ADVANCES IN SPACE MEDICINE
Editor: J.Colin
Published January 1977
122 pages

This publication contains 13 papers presented at a Specialists' Meeting of the Aerospace Medical Panel, held in Athens, Greece, 20–24 September 1976. A Technical Evaluation Report, in French and English, is included.

ISBN 92-835-0186-1

AGARD-CP-203

Aerospace medicine
Aerospace environment
Bioastronautics
Spacecraft environments
Psychology
Weightlessness
Motion sickness
Training
Flight crews

AGARD Conference Proceedings No.203
Advisory Group for Aerospace Research and Development, NATO
RECENT ADVANCES IN SPACE MEDICINE
Editor: J.Colin
Published January 1977
122 pages

This publication contains 13 papers presented at a Specialists' Meeting of the Aerospace Medical Panel, held in Athens, Greece, 20–24 September 1976. A Technical Evaluation Report, in French and English, is included.

ISBN 92-835-0186-1

AGARD-CP-203

Aerospace medicine
Aerospace environment
Bioastronautics
Spacecraft environments
Psychology
Weightlessness
Motion sickness
Training
Flight crews

AGARD

NATO OTAN

7 RUE ANCELLE · 92200 NEUILLY-SUR-SEINE

FRANCE

Telephone 745.08.10 · Telex 610176

DISTRIBUTION OF UNCLASSIFIED AGARD PUBLICATIONS

AGARD does NOT hold stocks of AGARD publications at the above address for general distribution. Initial distribution of AGARD publications is made to AGARD Member Nations through the following National Distribution Centres. Further copies are sometimes available from these Centres, but if not may be purchased in Microfiche or Photocopy form from the Purchase Agencies listed below.

NATIONAL DISTRIBUTION CENTRES

BELGIUM
Coordonnateur AGARD – VSL
Etat-Major de la Force Aérienne
Caserne Prince Baudouin
Place Dailly, 1030 Bruxelles

CANADA
Defence Scientific Information Service
Department of National Defence
Ottawa, Ontario K1A OZ2

DENMARK
Danish Defence Research Board
Østerbrogades K[illegible]
Copenhagen Ø[illegible]

FRANCE
O.N.E.R.A. (Direction)
29 Avenue de la Division Leclerc
92 Châtillon sous Bagneux

GERMANY
Zentralstelle für Luft- und Raumfahrt-dokumentation und -information
Postfach 860880
D-8 München 86

GREECE
Hellenic Armed Forces Command
D Branch, Athens

ICELAND
Director of Aviation
c/o Flugrad
Reykjavik

ITALY
Aeronautica Militare
Ufficio del Delegato Nazionale all'AGARD
3, Piazzale Adenauer
Roma/EUR

LUXEMBOURG
See Belgium

NETHERLANDS
Netherlands Delegation to AGARD
National Aerospace Laboratory, NLR
P.O. Box 126
Delft

NORWAY
Norwegian Defence Research Establishment
Main Library
P.O. Box 25
N-2007 Kjeller

PORTUGAL
Direccao do Servico de Material
da Forca Aerea
Rua de Escola Politecnica 42
Lisboa
Attn: AGARD National Delegate

TURKEY
Department of Research and Development (ARGE)
Ministry of National Defence, Ankara

UNITED KINGDOM
Defence Research Information Centre
Station Square House
St. Mary Cray
Orpington, Kent BR5 3RE

UNITED STATES
National Aeronautics and Space Administration (NASA),
Langley Field, Virginia 23365
Attn: Report Distribution and Storage Unit

THE UNITED STATES NATIONAL DISTRIBUTION CENTRE (NASA) DOES NOT HOLD STOCKS OF AGARD PUBLICATIONS, AND APPLICATIONS FOR COPIES SHOULD BE MADE DIRECT TO THE NATIONAL TECHNICAL INFORMATION SERVICE (NTIS) AT THE ADDRESS BELOW.

PURCHASE AGENCIES

Microfiche or Photocopy
National Technical
Information Service (NTIS)
5285 Port Royal Road
Springfield
Virginia 22151, USA

Microfiche
Space Documentation Service
European Space Agency
10, rue Mario Nikis
75015 Paris, France

Microfiche
Technology Reports
Centre (DTI)
Station Square House
St. Mary Cray
Orpington, Kent BR5 3RF
England

Requests for microfiche or photocopies of AGARD documents should include the AGARD serial number, title, author or editor, and publication date. Requests to NTIS should include the NASA accession report number. Full bibliographical references and abstracts of AGARD publications are given in the following journals:

Scientific and Technical Aerospace Reports (STAR),
published by NASA Scientific and Technical
Information Facility
Post Office Box 8757
Baltimore/Washington International Airport
Maryland 21240, USA

Government Reports Announcements (GRA),
published by the National Technical
Information Services, Springfield
Virginia 22151, USA

Printed by Technical Editing and Reproduction Ltd
Harford House, 7–9 Charlotte St, London W1P 1HD

ISBN 92-835-0186-1